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Department of Water Resources

BULLETIN NO. 16-67

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WEATHER MODIFICATION OPERATIONS IN CALIFORNIA

OCTOBER 1, 1966 - SEPTEMBER 30, 1967

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AUGUST 1968

NORMAN B. LIVERMORE, JR.
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RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
Director
Department of Water Resources

FOREWORD

California is a natural outdoor laboratory for weather modification. The Coast and Sierra Ranges induce an orographic effect which aids in maximizing weather modification opportunities and project efficiency. In addition, the State contains numerous reservoir systems -- now being augmented by the mammoth State Water Project -- to catch the artificially produced precipitation. Thus, it is not surprising that weather modification in California has had an active history of about two decades, and that some of the oldest continuous weather modification projects in the nation have been conducted in California.

Weather modification operations in California are governed by Chapter 4, Division 1, Sections 400 through 415 of the Water Code. These Water Code sections prescribe procedures for licensing contractors and for initiating and reporting a project. The sections also describe special cases and indicate penalties for violation of the statute. The Department of Water Resources administers the Water Code provisions governing weather modification operations in California.

This bulletin, the twelfth in a continuing series, describes weather modification projects and evaluation techniques in California, according to data in notices of intention, project completion reports, and project evaluation reports submitted to the Department under the Water Code requirements.

William R Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California

PHOTO CAPTIONS

LEFT: Silver Iodide Weather-Modification Station overlooking Lake Almanor Basin on the Feather River. Photo courtesy of Pacific Gas and Electric Company.

FRONT COVER: Seeded Rain Cloud. Photo courtesy of Atmospherics Incorporated.

BACK COVER: Silver Iodide Generator and Smoke Plume. Photo courtesy of Atmospherics Incorporated.

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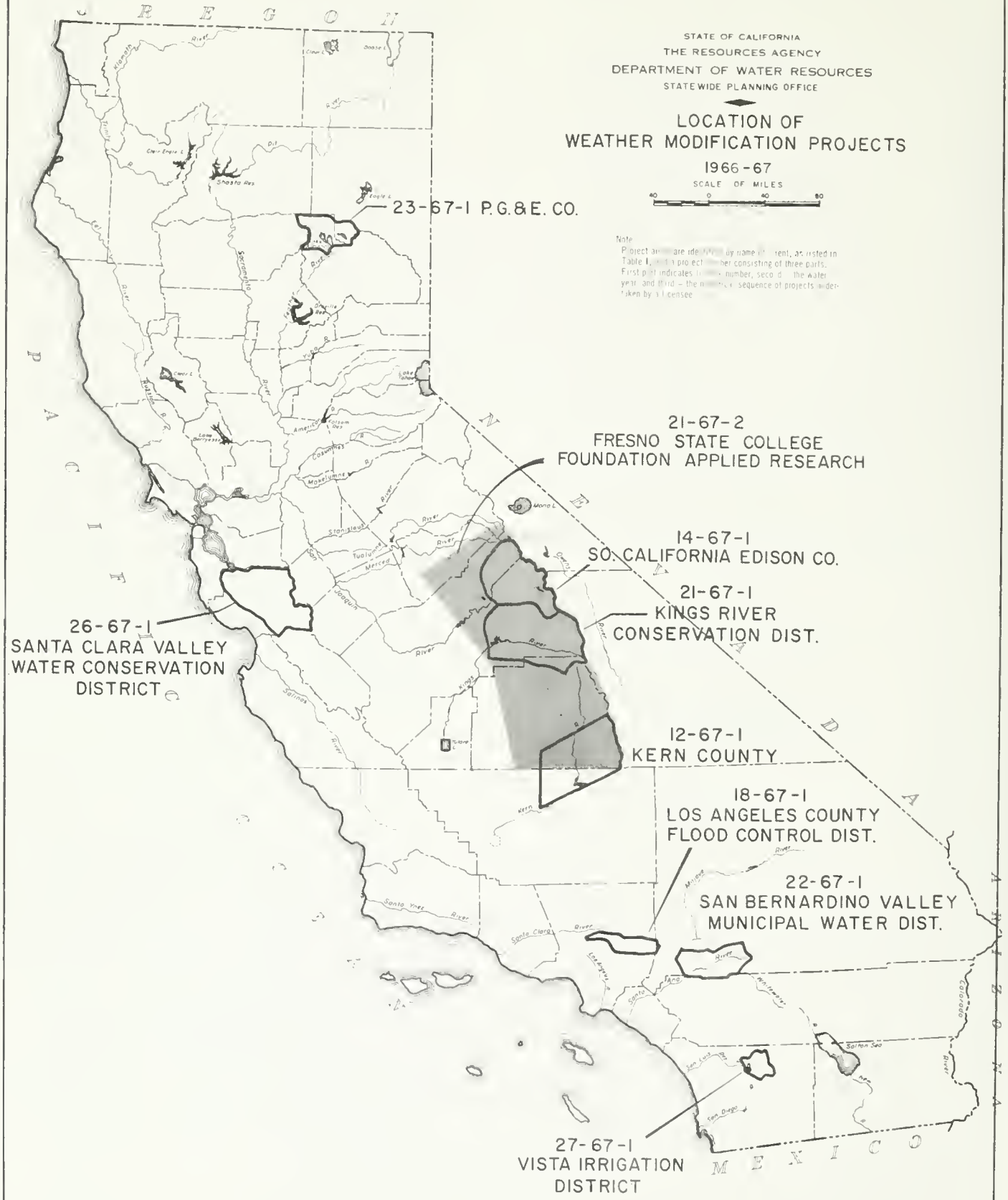
ABSTRACT

Eight California licensees conducted nine cloud-seeding projects during the 1966-67 water year. The projects were conducted mainly to increase surface storage for municipal and irrigation uses, for use in recreational facilities, and for use in hydroelectric installations. Additional purposes for precipitation increase were ground water storage and applied research. Five project target areas were in Central California, three in Southern California, and one in the northern Sierra Nevada.

Excluding electric discharge operations, 15,704 hours of cloud seeding were logged from ground-based equipment and 225 hours from aircraft. Seven licensees used silver iodide, dispersed from ground-based generators or aircraft, as a nucleation agent. In addition to silver iodide, one licensee dispersed 155 pounds of dry ice. One licensee used the electric discharge method, in which ions discharged from stainless steel wires act as a nucleation agent. This unit was operated during 235 days of the 1966-67 season.

ACKNOWLEDGMENTS

The Water Rights Engineering Section wishes to thank the weather modification licensees of California for their cooperation in supplying information on their cloud-seeding projects, particularly Pacific Gas and Electric Company, Atmospheric Water Resources Research, Santa Clara Valley Water Conservation District, and Atmospherics Incorporated for supplying illustrations, and Atmospheric Water Resources Research for permitting the reprinting of a summary report on the research program.


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
STATEWIDE PLANNING OFFICE
LOCATION OF
WEATHER MODIFICATION PROJECTS
1966-67
SCALE OF MILES
40 0 40 80
Note
Project areas are identified by name of client, as listed in Table I, and a project number consisting of three parts. First part indicates the project number, second the water year, and third – the numerical sequence of projects undertaken by a licensee.
OREGON
NEVADA
ARIZONA
MEXICO
PACIFIC
23-67-1 P.G.&E. CO.
21-67-2
FRESNO STATE COLLEGE
FOUNDATION APPLIED RESEARCH
14-67-1
SO. CALIFORNIA EDISON CO.
21-67-1
KINGS RIVER
CONSERVATION DIST.
26-67-1
SANTA CLARA VALLEY
WATER CONSERVATION
DISTRICT
12-67-1
KERN COUNTY
18-67-1
LOS ANGELES COUNTY
FLOOD CONTROL DIST.
22-67-1
SAN BERNARDINO VALLEY
MUNICIPAL WATER DIST.
27-67-1
VISTA IRRIGATION
DISTRICT

During the 1966-67 water year (October 1966 - September 1967), eight licensees conducted nine weather modification projects. Eight projects were conducted to increase precipitation for surface storage. One project, Project Sierra Cumulus, was an applied research effort.

The purpose of the Santa Clara Valley Cloud Seeding Project was to increase precipitation for ground water storage as well as for surface storage. In addition to increasing water supplies for municipal use and irrigation, the Upper Santa Ana River Watershed Weather Modification Project also benefited recreational facilities in the San Bernardino National Forest. The Kings River Weather Modification Program and the Artificial Modification of Atmospheric Space Charge at Warner Ranch, although conducted to increase precipitation for surface storage in reservoirs, included research efforts as well. Two weather modification projects -- the Upper San Joaquin River Basin Weather Modification Project and the Lake Almanor Cloud Seeding Project -- were conducted to increase runoff upstream from hydroelectric installations.

Most of the nine weather modification projects were conducted in central or southern California. Five projects were conducted in central California and three in southern California. One project, the Lake Almanor Cloud Seeding Project, was conducted in northern California. Locations of weather modification projects are shown in Figure 1.

The period of most intensive weather modification operations was November through April. However, Project Sierra Cumulus, conducted by Atmospherics Incorporated, extended from May through September. In addition, Vista Irrigation District operated its Artificial Modification of Atmospheric Space Charge at Warner Ranch during each month of the water year except September. Some weather modification operations thus occurred during every month of the 1966-67 season. Days of cloud seeding for each project are shown in calendar form in Figure 5 (pages 16 and 17).

Heaviest seeding, according to monthly totals of days of seeding -- excluding the project of Vista Irrigation District, in which continuous operation was attempted -- took place in March (23 days of operation) and April (25 days). Seeding occurred during 15 days in November, 11 in December, and 14 in January. Fewer than 10 days of seeding were recorded for each of the remaining months. Lightest seeding occurred in October (1 day) and May (2 days).

Excluding the project of Vista Irrigation District, which was operated on 235 days, seeding occurred during 121 days of the 1966-67 season. Seeding from ground-based equipment occurred on 96 days. Seeding from aircraft was recorded on 51 days. Total days of cloud seeding per month, together with monthly totals for ground-based equipment and for aircraft, are shown in Figure 2.

A total of 15,703.9 hours of seeding from ground-based equipment -- excluding operations of Vista Irrigation District, which were logged by days -- occurred during the

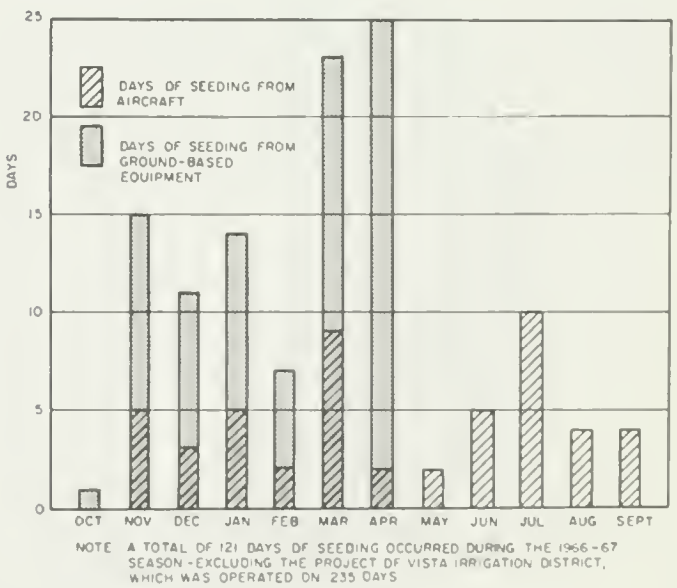


Figure 2. Total Days of Cloud Seeding Per Month in California, October 1, 1966 — September 30, 1967.

TABLE 1. SUMMARY OF WEATHER MODIFICATION PROJECTS IN CALIFORNIA, OCTOBER 1, 1966 - SEPTEMBER 30, 1967

Project Number (a)	Licensee	Client	Target Area	Purpose of Precipitation Increase
1-67-1	North American Weather Consultants	Southern California Edison Company	Upper San Joaquin River Basin	Storage in hydroelectric installations
12-67-1	Precipitation Control Company of California	Kern County	Upper Kern River Watershed	Surface storage
18-67-1	Los Angeles County Flood Control District	Los Angeles County Flood Control District	Drainage areas tributary to District's reservoirs	Surface storage
21-67-1	Atmospherics Incorporated	Kings River Conservation District	Kings River Watershed above Pine Flat Dam	Surface storage
21-67-2	Atmospherics Incorporated	Fresno State College Foundation	Southern Sierra Mountains	Applied research on orographic cumulus clouds
22-67-1	San Bernardino Valley Municipal Water District	San Bernardino Valley Municipal Water District	Upper Santa Ana River Watershed	Surface storage and recreation
23-67-1	Pacific Gas and Electric Company	Pacific Gas and Electric Company	Watersheds of Mountain Meadows and Butt Valley Reservoirs and Lake Almanor	Storage in hydroelectric installations
26-67-1	Santa Clara Valley Water Conservation District	Santa Clara Valley Water Conservation District	Santa Clara County	Surface and ground water storage
27-67-1	Vista Irrigation District	Vista Irrigation District	Lake Henshaw Watershed, San Diego County	Surface storage and research

(a) First number indicates license number; second - the water year; third - numerical sequence of projects undertaken by licensee.

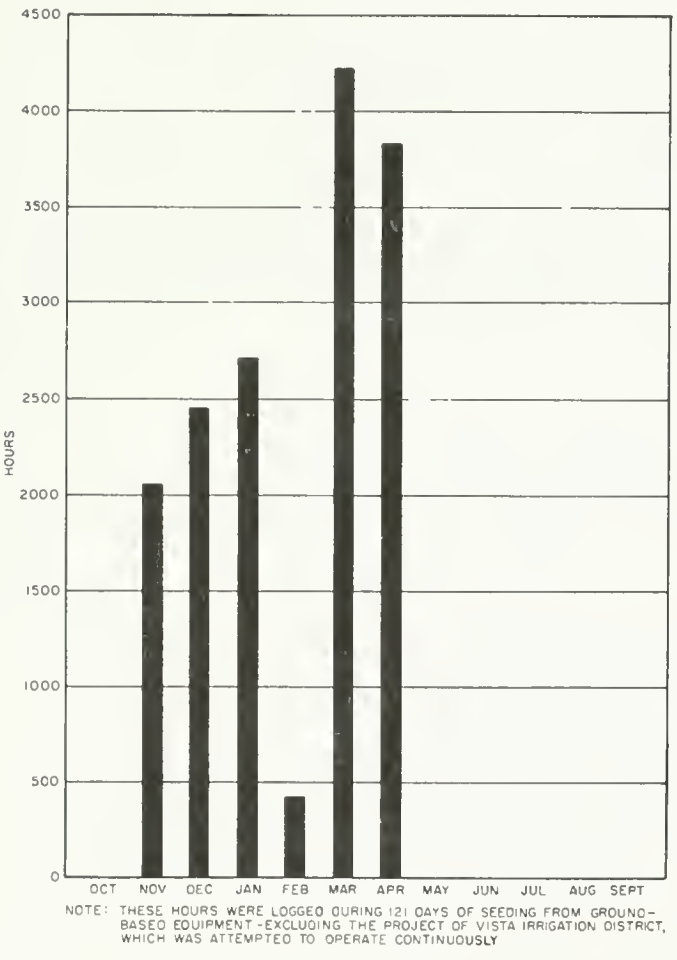


Figure 3. Total Hours of Cloud Seeding Per Month From Ground-Based Equipment, October 1, 1966 – September 30, 1967.

1966-67 season. For Vista Irrigation District's Artificial Modification of Atmospheric Space Charge at Warner Ranch, the electric discharge method was used. Other licensees used generators dispersing silver iodide. Two licensees, Atmospherics Incorporated (Kings River Weather Modification Program) and San Bernardino Valley Municipal Water District, used pyrotechnic devices in addition to regular ground generators.

Silver iodide seeding from ground-based equipment occurred from October through April; monthly hours of seeding were as follows:

October	5.0 hr	February	432.1 hr
November	2,061.8 hr	March	4,218.5 hr
December	2,456.5 hr	April	3,823.5 hr
January	2,706.5 hr	TOTAL	15,713.9 hr

Total hours of cloud seeding per month from ground-based equipment are shown graphically in Figure 3.

Seeding from aircraft totaled 224.8 hours during the 1966-67 season. Such seeding occurred during all months except October and April. Heaviest seeding from aircraft, according to monthly totals of hours of seeding, occurred during March (47.3 hours) and July (37.9 hours).

TABLE 2. SUMMARY OF PROJECT OPERATIONS IN CALIFORNIA
OCTOBER 1, 1966 - SEPTEMBER 30, 1967

Project No. (a)	Number of Generators	Grams of Silver Iodide per Hour per Generator: Ground Generators	Grams of Silver Iodide per Hour per Generator: Aircraft	Total Grams of Silver Iodide Dispersed: Ground Generators	Total Grams of Silver Iodide Dispersed: Aircraft	Total Generator Hours: Ground Generators	Total Generator Hours: Aircraft
1-67-1	12	6.0	--	31,364	--	5,227.3	--
12-67-1	--	--	42.5	--	--	--	100.0
18-67-1	14	6.0	--	--	--	1,837.5	--
21-67-1	25	12.0	--	18,730(b)	1,290	1,560.3	33.8
21-67-2	--	--	--	--	3,854(c)	--	91.0
22-67-1	17	10.0	--	16,158(d)	--	1,615.8	--
23-67-1	6	25.4	--	94,017	--	3,700.5	--
26-67-1	21	25.0	--	44,060	--	1,762.5	--
27-67-1(e)	--	--	--	--	--	--	--

(a) First number indicates license number; second, water year; third, numerical sequence of projects by licensee.
(b) In addition, licensee dispersed 1350 grams of silver iodide from pyrotechnic devices used on the ground during December, January, and April.
(c) In addition, licensee dispersed 155 pounds of dry ice.
(d) Includes 500 grams of silver iodide dispersed from pyrotechnic devices on the ground during April.
(e) Licensee used electric discharge method.

Lightest seeding occurred during May (9 hours) and September (10.7 hours). Total hours of cloud seeding per month from aircraft are shown in Figure 4.

Seven licensees used silver iodide, dispersed from ground-based generators, aircraft, or pyrotechnic devices used on the ground, as a nucleation agent. In addition to silver iodide, one of these licensees, Atmospherics Incorporated, dispersed 155 pounds of dry ice (CO_2 crystals) during its Project Sierra Cumulus. One licensee, Vista Irrigation District, used the electric discharge method, in which ions discharged from stainless steel wires act as a nucleation agent.

Weather modification projects are summarized in Table 1, and weather modification project operations are summarized in Table 2. Weather modification licensees during the 1966-67 water year are those listed in Table 3 with license numbers 1 through 27.

State and federal provisions governing weather modification operations may be found in Department of Water Resources Bulletin No. 16-65.

TABLE 3. WEATHER MODIFICATION LICENSES ISSUED FOR CALENDAR YEAR 1968

License Number and Licensee

1 North American Weather Consultants
Santa Barbara Municipal Airport
Goleta, California 93017

5 Water Resources Development Corporation
611 S. Palm Canyon Drive, Suite 216
Palm Springs, California 92262

12 Precipitation Control Company of California
105 Pierce Street
Taft, California 93268

18 Los Angeles County Flood Control District
P. O. Box 2418, Terminal Annex
Los Angeles, California 90033

21 Atmospherics Incorporated
3435 E. Pontiac Way
Fresno, California 93726

22 San Bernardino Valley Municipal Water District
355 North D Street, P. O. Box 1144
San Bernardino, California 92402

23 Pacific Gas and Electric Company
245 Market Street
San Francisco, California 94106

24 International Weather Control, Inc.
40 West First Street, Suite 104
Reno, Nevada 89501

25 K. R. C. Service Corporation
2956 C Street
San Diego, California 92102

26 Santa Clara Valley Water Conservation District
15420 Almaden Road
San Jose, California 95118

27 Vista Irrigation District
P. O. Box 1088
Vista, California 92083

28 Weather Science, Inc.
1808 Newton Drive
Norman, Oklahoma 73069

29 World Weather, Inc.
1510 Ranson Drive
Houston, Texas 77055

30 Fresno State College Foundation
Atmospheric Water Resources Research
Fresno State College
Fresno, California 93726

*License numbers 1 through 27 were active October 1966 - September 1967; license numbers 28, 29, and 30 were issued subsequent to the 1966-67 water year.

A summary report on the extensive weather modification research program undertaken by Atmospheric Water Resources Research, Fresno State College Foundation, is reprinted, by permission of Atmospheric Water Resources Research, in Appendix A.

Since weather modification operations to some extent reflect precipitation patterns, statewide precipitation for the 1966-67 water year (October 1966 through September 1967) is summarized in Appendix B.

Weather modification licenses issued for calendar year 1968 are listed in Table 3.

Reports and papers mentioned in Bulletin 16-67 as providing additional information on individual weather modification projects may be obtained from the licensees who operated the projects. However, licensees may release or withhold this material at their own discretion.

Telemetered Tipping Bucket Rain Gage

TABLE 4. GENERATOR-HOURS OF OPERATION BY MONTH, PROJECT 1-67-1

Location	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
Florence	5.0	79.8	45.7	72.5	25.5	114.0	255.0	597.5
Vermillion	0	52.0	45.0	72.5	25.5	116.0	228.5	539.5
China Peak	0	87.3	86.5	89.0	20.2	174.2	258.0	715.2
Mr. Given	0	116.7	92.0	89.0	25.5	185.8	258.0	767.0
Huntington	0	122.5	92.0	89.0	20.2	174.3	258.0	756.0
Mammoth	0	114.0	86.5	0	0	0	0	200.5
Shaver	0	67.5	40.5	89.0	20.3	167.5	231.2	616.0
Pine Ridge	0	35.5	35.0	21.2	0	79.0	65.8	236.5
Auberry	0	44.5	56.0	32.5	0	58.8	40.0	231.8
Tollhouse	0	34.0	36.0	32.5	0	0	66.3	168.8
South Fork	0	44.5	55.5	31.3	0	30.2	16.0	177.5
Bass Lake	0	20.5	57.5	21.3	0	46.0	75.7	221.0
TOTAL	5.0	818.8	728.2	639.8	137.2	1,145.8	1,752.5	5,227.3

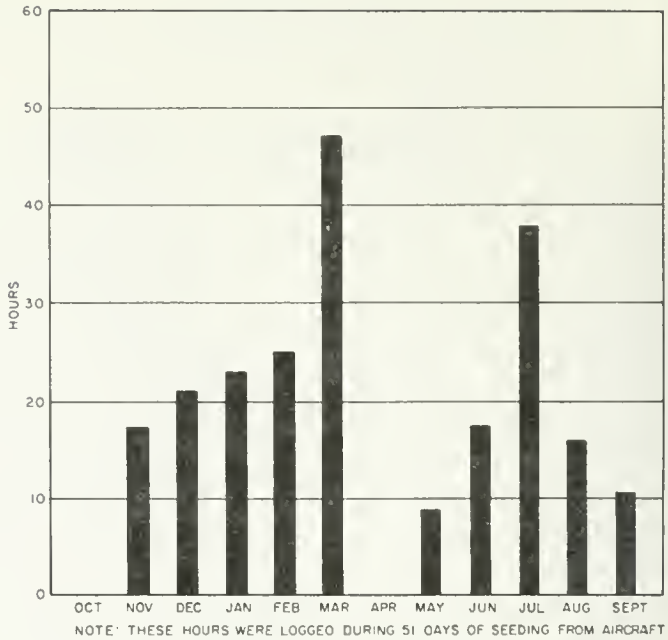


Figure 4. Total Hours of Cloud Seeding per Month From Aircraft, October 1, 1966 – September 30, 1967.

TABLE 5. GENERATOR-HOURS OF OPERATION BY DAY, PROJECT 1-67-1

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1	0	0	115.1	0	0	0	120.0
2	0	0	170.0	0	0	0	113.3
3	0	0	73.9	0	0	63.0	0
4	0	0	45.5	0	0	64.8	154.5
5	0	0	199.2	0	0	0	73.3
6	0	79.0	102.5	0	0	0	152.7
7	0	76.5	22.0	0	0	0	158.5
8	0	22.5	0	0	0	0	0
9	0	0	0	0	0	0	0
10	5.0	0	0	0	0	18.0	66.0
11	0	0	0	0	0	101.1	115.7
12	0	0	0	0	0	168.8	0
13	0	0	0	0	0	212.5	0
14	0	0	0	0	12.0	64.0	0
15	0	0	0	0	15.0	55.5	109.2
16	0	69.2	0	0	0	83.8	0
17	0	0	0	0	0	0	42.0
18	0	0	0	0	0	0	144.0
19	0	48.5	0	0	0	0	144.0
20	0	132.5	0	78.5	0	0	64.0
21	0	24.2	0	166.7	0	0	116.8
22	0	99.0	0	124.0	0	0	64.5
23	0	0	0	144.2	0	14.4	26.0
24	0	0	0	126.4	22.6	0	88.0
25	0	0	0	0	87.0	0	0
26	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0
28	0	179.2	0	0	0	51.3	0
29	0	88.2	0	0	-	16.4	0
30	0	0	0	0	-	64.2	0
31	0	-	0	0	-	168.0	-
TOTAL	5.0	818.8	728.2	639.8	137.2	1,145.8	1,752.5

TABLE 6. SUMMARY OF OPERATIONS, PROJECT 1-67-1

Month	Seeding periods	Days of seeding	Hours of seeding
October	1	1	5.0
November	6	10	818.8
December	3	7	728.2
January	3	5	639.8
February	3	4	137.2
March	6	14	1,145.8
April	9	17	1,752.5
TOTAL	31	58	5,227.3

During the 1966-67 water year, the Department of Water Resources issued 11 weather modification licenses and 8 licensees conducted 9 projects. Information submitted to the Department on the projects varied from minimum data required by state law to detailed project completion and evaluation reports. These detailed reports, in addition to daily logs, included descriptions of storms, physical features of target areas, equipment, and methods of evaluation; and photographs, charts, graphs, maps, and other information of interest. The following project descriptions are derived from notices of intention, and project completion and evaluation reports submitted to the Department by licensees.

Upper San Joaquin River Basin Weather Modification Project (1-67-1)

Between October 10, 1966, and April 24, 1967, North American Weather Consultants (License No. 1) conducted weather modification project operations for Southern California Edison Company. This project, which has been operated for 16 consecutive years, was conducted to increase snowpack. Equipment was operated in the vicinity of Mammoth Pool, Huntington Lake, Shaver Lake, Florence Lake, Lake Thomas A. Edison, and Kaiser Pass and adjacent foothill areas in Fresno and Madera Counties. The target area was the drainage area of the Upper San Joaquin River and its tributaries in Fresno County. The basin of the San Joaquin River above Powerhouse No. 8 and adjacent foothill areas were also possibly affected by the project.

Project equipment included 12 ground-based radio-controlled generators emitting silver iodide at a rate of 6 grams per hour per generator. Generator locations remained the same as for the 1965-66 season. The target area and generator locations are shown in Figure 6.

Monthly totals of generator-hours for each project generator are given in Table 4 (page 10). Distribution of generator-hours by day is given in Table 5.

Operations were carried out during 31 storms, compared with 40 storms during the 1965-66 season. Nine storms occurred in April; six each during December and March; three each during November, January and February; and one in October.

During the project, 31,364 grams of silver iodide was dispersed. Project operations are summarized in Table 6.

Kern River Watershed Weather Modification Project (12-67-1)

Between November 16, 1966, and March 31, 1967, Precipitation Control Company of California (License No. 12) conducted weather modification project operations for Kern County. This project was conducted to increase streamflow in the Kern River watershed.

Project equipment included a Cessna 310 aircraft dispersing silver iodide at a rate of approximately 1.5 ounces per hour. The aircraft was operated for 100 hours during 43 flights compared to

Figure 6. Target Area and Generator Locations, Project 1-67-1

100 hours logged in 50 flights during the 1965-66 season. On nine flights during the project, no seeding was conducted. Distribution of aircraft-hours by day is given in Table 7.

Artificial Nucleation Program in the San Gabriel River, Big Tujunga, and Pacoima Drainage Basins (18-67-1)

Between November 11, 1966, and April 22, 1967, Los Angeles County Flood Control District (License No. 18) conducted weather modification project operations on its own behalf. This project was conducted to increase precipitation at certain locations in the San Gabriel Mountains. Equipment was operated in areas adjacent to the drainage areas tributary to district-owned dams. The target area was in the San Gabriel Mountains and adjacent to district-owned dams extending from Pacoima Dam on the west to Thompson Creek Dam on the east. Mountainous areas lying generally northward from the southern foothills of the San Gabriel Mountains between the City of San Fernando and the City of Claremont were possibly affected by the project.

Project equipment included 16 ground-based generators burning a 2 percent solution of silver iodide at a rate of 6 grams per hour per generator. The generators were located mainly to the south of the target area. Generator locations were unchanged from the 1965-66 season. The target area and generator locations for this project are shown in Figure 7.

Monthly totals of generator-hours for each project generator are given in Table 8. Distribution of generator-hours by day is given in Table 9.

During the project, 16 storm periods occurred, an average of 2 per month during November through March and 6 (4

TABLE 7. AIRCRAFT-HOURS OF OPERATION BY DAY, PROJECT 12-67-1

Day	Nov	Dec	Jan	Feb	Mar
1	0	0	0	0	0
2	0	3.5	0	0	0
3	0	1.0	0	0	2.3
4	0	6.3	0	0	4.2
5	0	8.2	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	8.8
12	0	0	0	0	4.8
13	0	0	0	0	4.6
14	0	0	0	6.8	0
15	0	0	0	0	0
16	0.5	0	0	0	0.8
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	7.0	0	0	0	0
21	0	0	0	0	0
22	3.0	0	6.6	0	0
23	0	0	0	0	0
24	0	0	6.2	0	0
25	0	0	0.7	5.2	0
26	0	0	0	0	0
27	0	0	0	0	0
28	2.1	0	0	0	5.1
29	0	0	1.5	-	0
30	0	0	4.6	-	4.0
31	-	0	0	-	2.2
TOTAL	12.6	19.0	19.6	12.0	36.8

100 HOURS GRAND TOTAL

TABLE 8. GENERATOR-HOURS OF OPERATION BY MONTH, PROJECT 18-67-1

Location	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Pacoima	0	0	0	0	0	0	0	0
La Tuna	0	0	0	0	0	0	0	0
Pickens	0	0	10.2	0	13.8	36.2	0	60.2
Devils Gate	0	58.8	19.0	0	32.0	56.5	0	166.3
Eaton Yard	17.0	46.2	10.8	3.5	17.0	50.3	0	144.8
Longden Yard	15.2	45.2	10.7	3.8	24.8	24.0	0	123.7
Ben Lomond	16.8	24.0	21.5	5.2	49.5	36.0	0	153.0
Puddingatone	10.0	0	20.5	0	41.7	17.0	0	89.2
Thompson Creek	10.5	0	8.8	0	26.0	0	0	45.3
Baldy G.S.	10.0	0	6.2	0	0	0	0	16.2
Tanbark Flats	9.8	0	9.5	4.0	29.2	19.0	0	71.5
Pine Mountain	8.7	58.5	24.3	4.2	93.5	80.8	0	270.0
Spring Camp	8.8	58.5	32.0	4.2	94.5	107.0	0	305.0
Mt. Wilson	0	0	8.0	4.3	94.5	106.7	0	213.5
Red Box	0	0	8.0	0	17.3	98.7	0	124.0
Tujunga	0	0	0	0	0	54.8	0	54.8
TOTAL	106.8	291.2	189.5	29.2	533.8	687.0	0	1,837.5

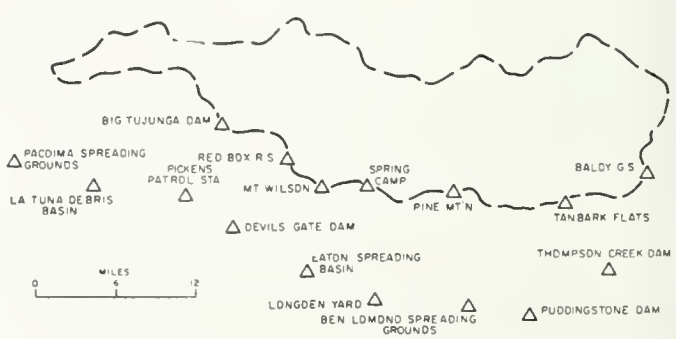


Figure 7. Target Area and Generator Locations, Project 18-67-1

major) in April. December, however, was the wettest month. A summary of project operation is given in Table 10.

The project was evaluated by three methods, all based upon comparison of historical nonseeded precipitation amounts at a valley control station with seeded precipitation amounts at a target station. Evaluation was thus limited to stations having long and reliable records, and was based upon the assumption of climatic continuity.

The first method of evaluation -- a method also used during the 1965-66 season -- focused attention on the peak precipitation period during historical nonseeded cases and during project seeded cases. A peak precipitation period was designated as the seven-hour period beginning with the third hour prior to the hour of peak precipitation. The peak precipitation period was considered the period during which seeding would produce the greatest increase in precipitation. Analyses were made by using the total precipitation during the peak precipitation periods for seeded and nonseeded cases selected for ten stations. For nine of the ten stations, increases of 17 to 36 percent were indicated. One station (Loomis Ranch) apparently recorded a 14 percent decrease. A rank sum test was applied to determine the statistical significance of the indicated excesses during peak precipitation periods. Only one station (Waterman G.S.) showed a statistically significant increase. Increases at the remaining eight stations may have been due to chance.

The second method of evaluation concentrated on comparison of total storm precipitation for historical nonseeded cases and project seeded cases. It was considered -- extending the concept that greatest effect from seeding occurs during peak precipitation intensity during a storm -- that seeding effects would be greatest for storms of greatest intensity. Therefore, historical and seeded storms were stratified to include only those for which the average control storm total of precipitation was greater than 2.00 inches. Ten historical storms occurring during the period 1950-57 and eight seeded storms occurring during the period 1961-66 were used in the analysis. A rank sum test on seeded and nonseeded cases was performed. Precipitation in the seeded group exceeded that in the nonseeded group by 38 percent, significant at the 0.025 (2.5 percent) level in a one-tailed test. Thus, concludes an evaluation report prepared by North American Weather Consultants, seeding apparently produced sizable increases in precipitation for the heaviest storms moving through the San Gabriels.

TABLE 9. GENERATOR-HOURS OF OPERATION BY DAY, PROJECT 1c-67-1

Day	Nov	Dec	Jan	Feb	Mar	Apr	May
1	0	0	0	0	0	147.8	0
2	0	45.0	0	0	0	52.8	0
3	0	102.5	0	0	0	0	0
4	0	2.7	0	0	0	100.5	0
5	0	113.8	0	0	0	0	0
6	0	27.2	0	0	0	0	0
7	70.8	0	0	0	0	0	0
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	2.2	0
11	0	0	0	0	135.0	45.0	0
12	0	0	0	0	148.5	0	0
13	0	0	0	0	124.8	0	0
14	0	0	0	0	24.2	35.0	0
15	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0
18	0	0	0	0	0	71.2	0
19	0	0	0	0	0	110.8	0
20	36.0	0.	0	0	0	0	0
21	0	0	0	0	0	60.5	0
22	0	0	91.8	0	0	41.2	0
23	0	0	0	0	0	0	0
24	0	0	66.0	0	0	0	0
25	0	0	0	0	0	0	0
26	0	[illegible]	0	0	0	0	0
27	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0
29	0	0	0	29.2	0	0	0
30	0	0	31.7	0	0	0	0
31	-	0	0	0	101.3	0	0
TOTAL	106.8	291.2	189.5	29.2	533.8	687.0	0

TABLE 10. SUMMARY OF OPERATIONS, PROJECT 18-67-1

Month	Seeding Periods	Days of seeding	Hours of seeding
November	2	2	106.8
December	2	5	291.2
January	3	3	189.5
February	1	1	29.2
March	2	5	533.8
April	6	10	687.0
May	0	0	0
TOTAL	16	26	1,837.5

The third method of evaluation was an examination of storm precipitation totals for all seeded periods for which totals at Burbank and Los Angeles exceeded 0.25 inches. A rank sum test was applied to apparent increases. This method was believed to give the most representative estimate of seeding effectiveness. The results of this method of analysis were in general compatible with those of the analysis of peak precipitation periods. However, the analysis of peak precipitation periods indicated that the greatest precipitation increase (38 percent) occurred over the eastern section of the target area. The analysis of all seeded periods, however, showed a more uniform distribution of increases (11 to 24 percent) over the target area as a whole, and indicated that the greatest increase occurred over the front range of the San Gabriels in the western section of the target area.

In estimating net precipitation increase for the 1966-67 season, use was made of the analysis of high-intensity storms and the analysis of all seeded periods. According to the report prepared by North American Weather Consultants, more than 75 percent of the target area received precipitation increases of about 20 percent. Amounts of precipitation increases ranged from 6 to 9 inches over a major portion of the target area, except for a small area near Loomis Ranch where no increase was noted. Estimated net increases in precipitation due to seeding are shown for various portions of the target area in Figure 8.

Los Angeles County Flood Control and Water Conservation District submitted to the Department an evaluation report prepared by North American Weather Consultants entitled, "Analysis of an Artificial Nucleation Program in the San Gabriel River, Big Tujunga, and Pacoima Drainage Basins: 1966-67 Season" (Report No. 6-68; August 1967).

Kings River Weather Modification Program (21-67-1)

Between November 6, 1966, and April 22, 1967, Atmospherics Incorporated (License No. 21) conducted weather modification project operations for the Kings River Water Conservation District. This project was conducted to increase precipitation for surface storage. Equipment was operated in parts of Fresno, Kings, Tulare, and Inyo Counties, and the target area was the Kings River watershed above Pine Flat Reservoir. In addition to the target area, parts of Fresno and Tulare Counties, which include the Kings River and certain tributary streams above

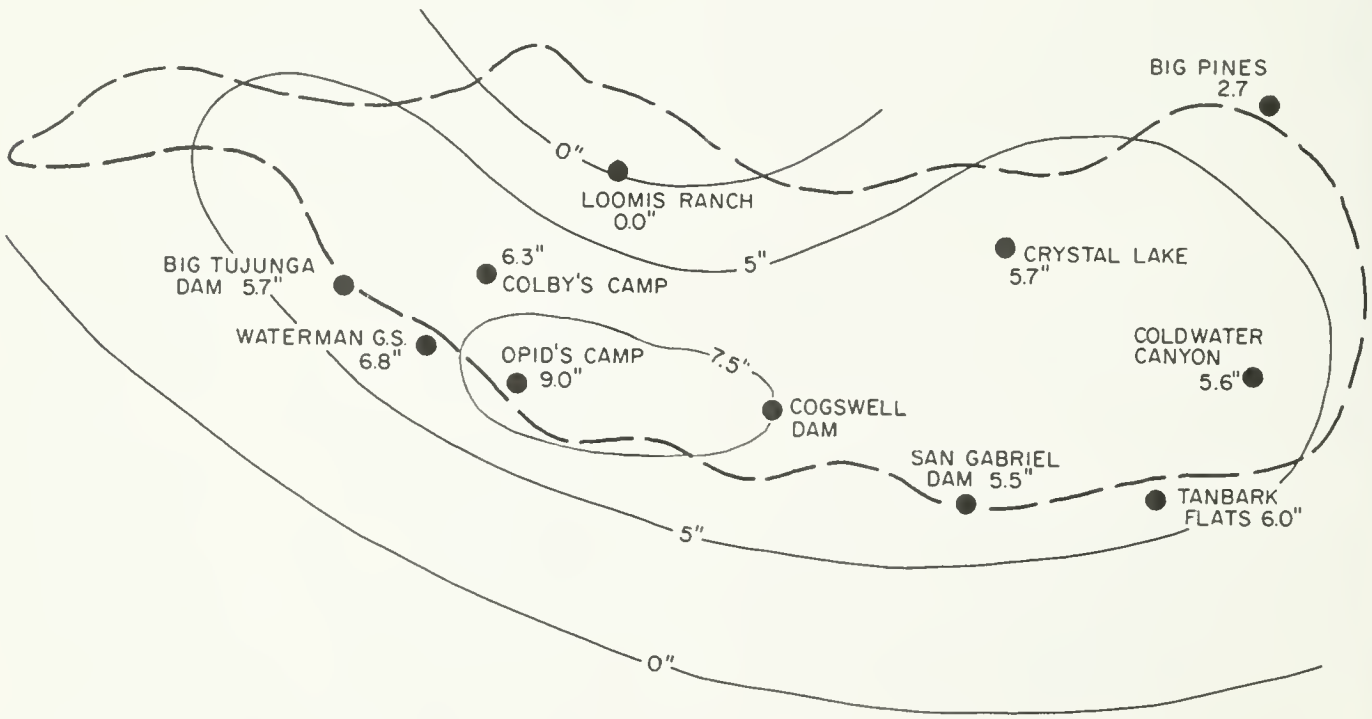


Figure 8. Estimated Net Increase in Precipitation Due to Seeding, Project 18-67-1

Pine Flat Reservoir, were possibly affected by the project. The target area for this project is shown in Figure 9.

Project equipment included 25 aspirator-type propane ground generators. By contrast, the network for the 1965-66 season comprised 30 generators. The ground generators burned a 2 percent solution of silver iodide in acetone at about 1800° F at a rate of 12 grams of silver iodide per hour per generator. The units were calibrated to provide an output of approximately 10^{15} nuclei per gram of silver iodide. Propane pressure was set at 10 pounds per square inch through a #60 standard gas orifice, with a resultant use rate of approximately 0.7 gallons per hour.

Generator units in the northern portion of the target area were placed at Wishon Dam, Balch Camp, Piedra, and Watts Valley. Those along the southern boundary of the target area -- the main line of generators -- were located on Highway 180 from the Friant-Kern Canal crossing to Cherry Gap, which is over 6,000 feet in elevation. Other generators were placed in the area of Hills Valley Road, Badger, and the Pinehurst Ranger Station. Minor changes were made in generator locations established during previous seasons.

The terrain of the Kings River watershed makes difficult the positioning of ground generators in a manner providing complete nuclei coverage of the target area. This operational difficulty, together with the occurrence of rapid cloud developments and fast-moving storms, was partially overcome by means of seeding from an aircraft. A turbocharged Piper Aztec "C" aircraft equipped with advanced navigational aids, including Distant Measuring Equipment and radar transponder, was used for seeding. The aircraft also had deicing equipment for high-altitude (up to 30,000 feet above sea level) all-weather flying. In contrast, during the 1965-66 season, a twin-engine Piper Apache, similarly equipped, was used for seeding from the air. Aircraft seeding flights were generally conducted within a 20-mile radius of the target area, near cloud base between the +3°C and the -5°C levels.

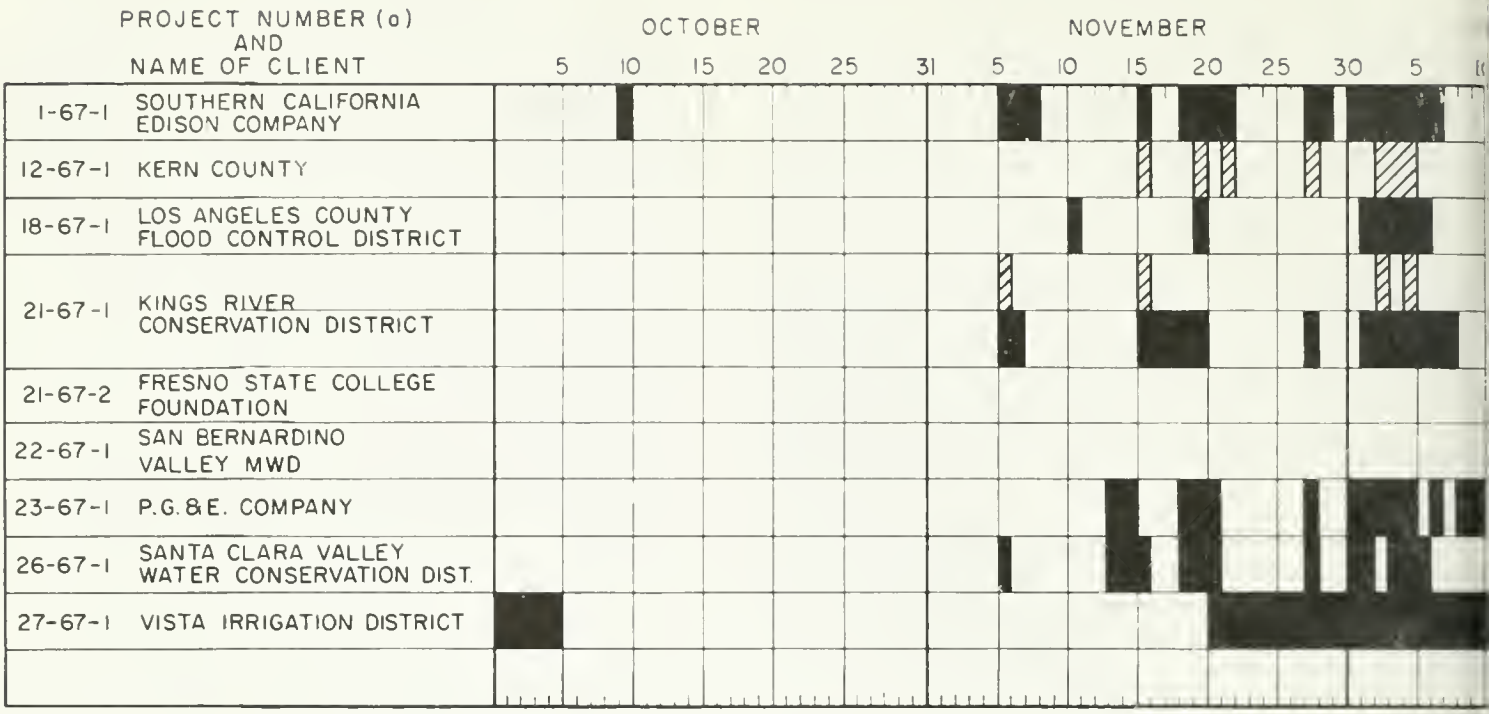
Figure 9. Target Area, Project 21-67-1

Ninety-six pyrotechnic nuclei generators ignited on the ground were also used for seeding. The pyrotechnic devices were solid-fuel flare-type units with silver iodide included in the flammable mix. The pyrotechnic devices produce larger freezing nuclei than the Wells-Fuquay generators. However, the efficiency of the two types of units is about the same at higher temperatures. Atmospherics Incorporated considers that in future operations aspirator-type generators may be phased out and replaced with pyrotechnic devices.

Monitoring equipment comprised a mobile radar unit -- also used for research purposes -- installed about 14 miles ENE of Fresno. This field headquarters, at an elevation of 350 feet above sea level, provided a view of the entire Kings River watershed. Storms approaching the Fresno area from the west were observed and tracked into the higher mountain country to the east.

The radar unit operated on a frequency of 9,400 megacycles with a peak power of 50,000 watts. It had a maximum range of 200 miles in steps of 10, 20, 80 and 200 miles. The system included two 7-inch plan position indicators. One indicator was used for general viewing during all storm periods and the other, for time-lapse photography. Data were documented with a 16-mm camera.

In addition, a network of small rain gages was placed along Highway 180 at elevations between 600 and 5,200 feet.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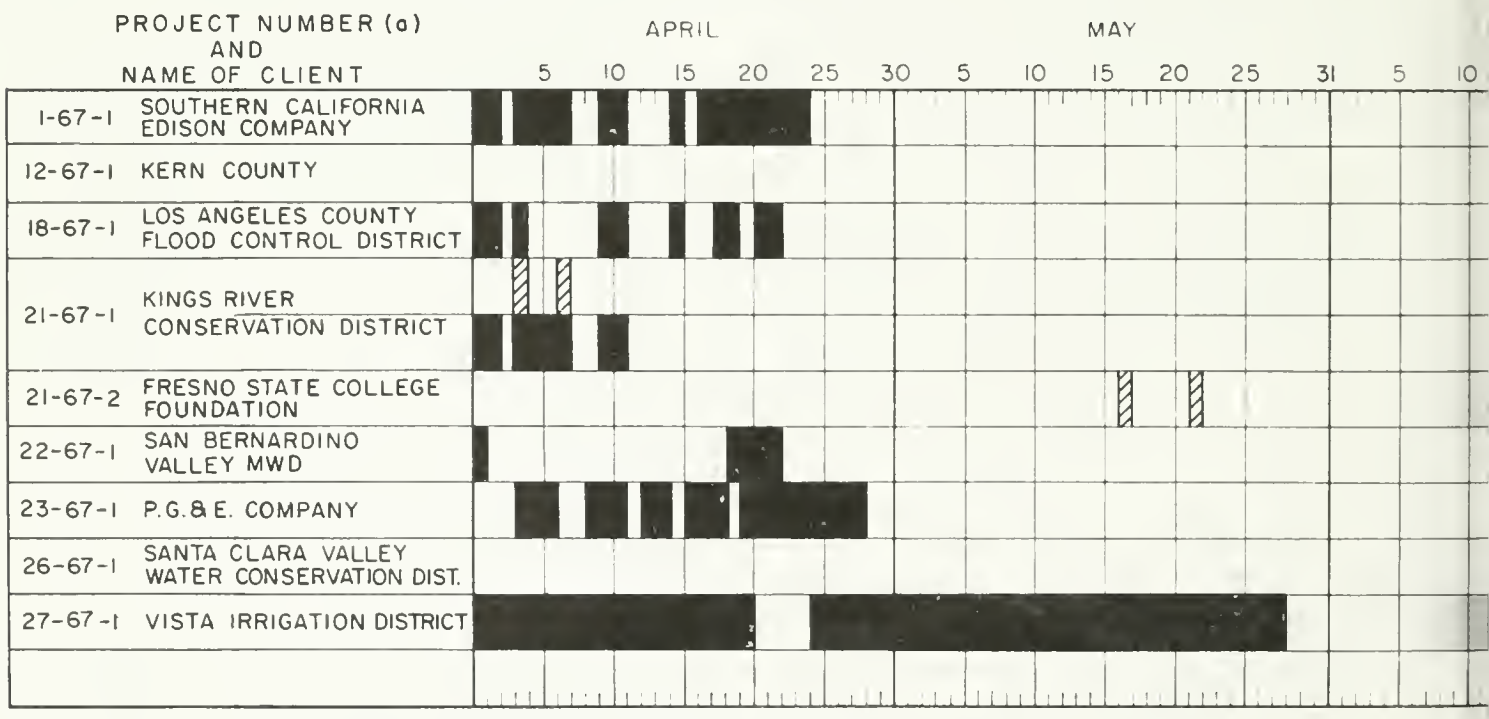
OCTOBER
NOVEMBER
5 10 15 20 25 31 5 10 15 20 25 30 5
1-67-1 SOUTHERN CALIFORNIA EDISON COMPANY
12-67-1 KERN COUNTY
18-67-1 LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
21-67-1 KINGS RIVER CONSERVATION DISTRICT
21-67-2 FRESNO STATE COLLEGE FOUNDATION
22-67-1 SAN BERNARDINO VALLEY MWD
23-67-1 P.G.&E. COMPANY
26-67-1 SANTA CLARA VALLEY WATER CONSERVATION DIST.
27-67-1 VISTA IRRIGATION DISTRICT

1966

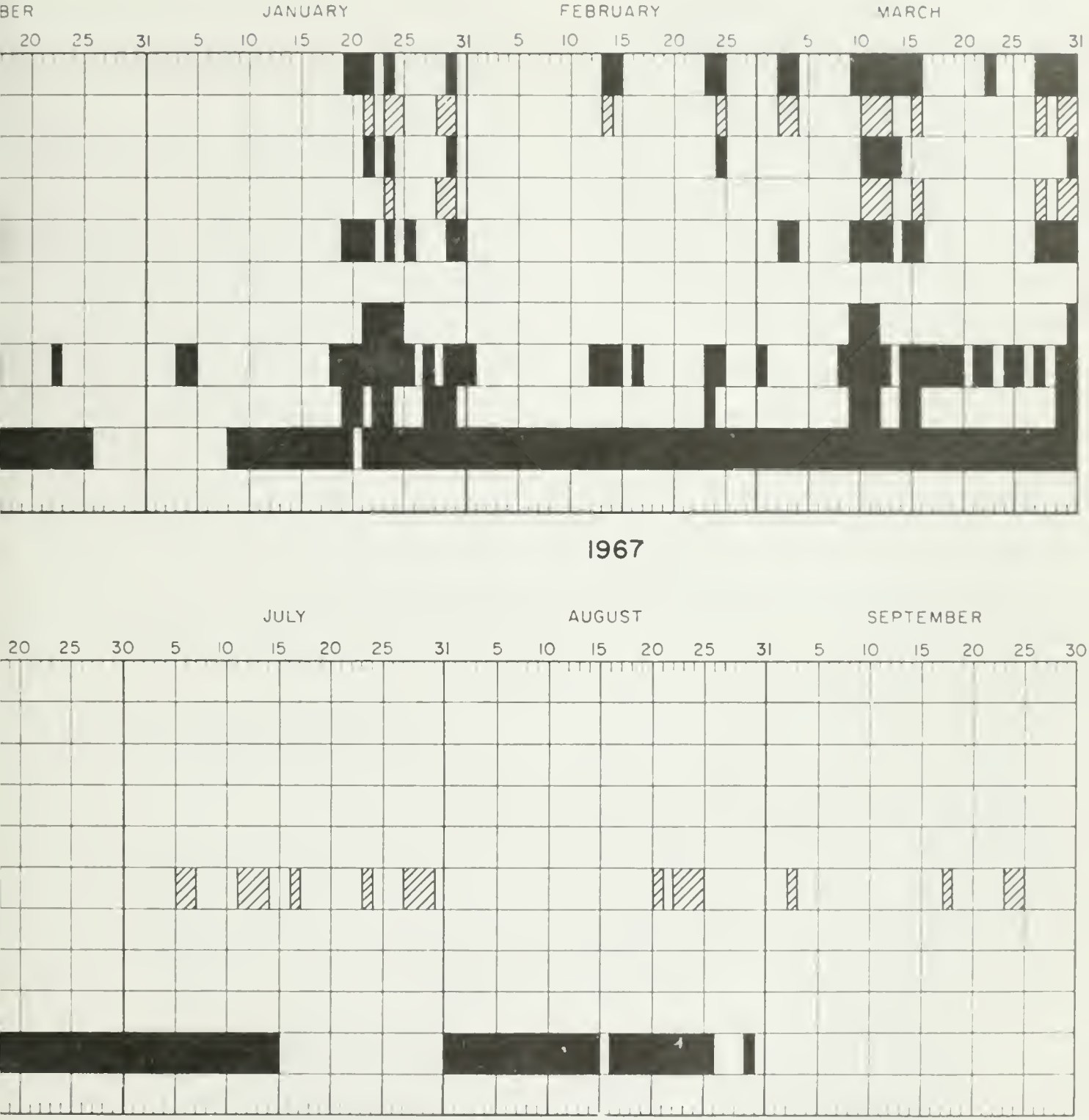

PROJECT NUMBER (a) AND NAME OF CLIENT
APRIL
MAY
5 10 15 20 25 30 5 10 15 20 25 31 5 10
1-67-1 SOUTHERN CALIFORNIA EDISON COMPANY
12-67-1 KERN COUNTY
18-67-1 LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
21-67-1 KINGS RIVER CONSERVATION DISTRICT
21-67-2 FRESNO STATE COLLEGE FOUNDATION
22-67-1 SAN BERNARDINO VALLEY MWD
23-67-1 P.G.&E. COMPANY
26-67-1 SANTA CLARA VALLEY WATER CONSERVATION DIST.
27-67-1 VISTA IRRIGATION DISTRICT

(a) Project number consists of three parts: first part indicates license number, second – the water year; and third – numerical sequence of projects undertaken by a licensee.

A

G

Figure 5



1967 WEATHER MODIFICATION OPERATIONS IN CALIFORNIA

T

DAYS OF CLOUD SEEDING

BASED GENERATORS

OCTOBER 1966 THROUGH SEPTEMBER 1967

Rainfall totals were collected after each storm.

The generators dispersed 18,723 grams of silver iodide. Monthly totals of generator-hours for each project generator are given in Table 11. Distribution of generator-hours by day is given in Table 12. The aircraft was operated for 33.8 hours during 23 flights, in contrast to 24.9 hours logged in 24 flights during the 1965-66 season. A total of 1,390 grams of silver iodide was dispersed from the aircraft. Pyrotechnic seeding devices used on the ground were employed for 19 hours during the project, dispersing 960 grams of silver iodide.

Twenty-six storms -- 21 of them seedable -- moved through or affected the target area during the period of operations. Twenty of these storms were seeded. One storm occurring on Christmas, one weak storm in February, and four storms in April were not seeded. In contrast, 20 storms moved through or affected the target area during the 1965-66 season. Project operations are summarized in Table 13.

According to an evaluation of the project by Atmospherics Incorporated, a statistical analysis of 1966-67 streamflow figures as given by the U. S. Geological Survey indicates an apparent increase of 1,700 acre-feet due to cloud seeding. An increase of 159,070 acre-feet took place during the 1965-66 season. Evaluations made each year of the 13-year period of the weather modification program indicate that seeding produced a total apparent increase of 922,870 acre-feet in Kings River flow, an average increase of 71,000 acre-feet yearly.

Besides the usual completion report, Atmospherics Incorporated submitted to the Department an evaluation report entitled, "Cloud Seeding on the Kings River Watershed: Final Report on the 1966-67 Season with Review of Results for Water Years 1956-67". Additional information concerning the project has

TABLE 11. GENERATOR-HOURS OF OPERATION BY MONTH, PROJECT 21-67-1

Location	Nov	Dec	Jan	Feb	Mar	Apr	Total
Flatland	0	0	4.0	0	0	10.0	14.0
Foothills	0	0	4.0	0	0	10.1	14.1
Bear Mt. Turnoff	0	24.0	4.0	0	0	36.1	64.1
Millview	0	60.0	0	0	0	10.1	70.1
Helicopter Pad	0	60.0	0	0	0	0	60.0
Sequoia Lake	6.0	60.0	0	0	0	0	66.0
Cherry Gap #1	14.0	48.0	0	0	0	0	62.0
Cherry Gap #2	0	0	14.0	0	0	0	14.0
Sequoia Road #1	6.0	0	0	0	24.0	0	30.0
Sequoia Road #2	9.0	0	39.0	0	25.5	0	73.5
Stoney Creek	9.0	0	23.6	0	42.5	0	75.1
Lodgepole	0	0	27.3	0	26.0	0	53.3
Giant Forest	0	0	12.3	0	17.0	30.0	59.3
Pinehurst	24.5	23.0	25.1	0	54.0	0	126.6
Badger #1	23.5	57.0	0	0	5.0	20.0	105.5
Badger #2	0	0	11.5	0	67.0	14.0	92.5
Hackett Ranch	32.5	22.5	0	0	0	0	55.0
Radar	0	0	3.8	0	66.5	32.1	102.4
Piedra	13.0	22.5	13.0	0	21.5	31.1	101.1
Trimmer #1	0	4.5	0	0	16.0	4.0	24.5
Trimmer #2	0	0	23.0	0	38.0	32.1	93.1
Balch #1	48.0	0	0	0	16.0	0	64.0
Balch #2	0	0	23.0	0	21.0	32.1	76.1
Wilson #1	48.0	0	0	0	16.0	0	64.0
Wilson #2	0	0	0	0	0	0	0
TOTAL	233.5	381.5	227.6	0	456.0	261.7	1,560.3

TABLE 12. GENERATOR-HOURS OF OPERATION BY DAY, PROJECT 21-67-1

Day	Nov	Dec	Jan	Feb	Mar	Apr	Total
1	0	0	0	0	0	3.5	3.5
2	0	63.5	0	0	0	36.8	100.3
3	0	32.0	0	0	12.0	0	44.0
4	0	19.5	0	0	21.0	51.2	91.7
5	0	113.5	0	0	0	31.0	144.5
6	14.3	124.5	0	0	0	25.0	163.8
7	14.7	28.5	0	0	0	39.0	82.2
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	30.0	19.5	49.5
11	0	0	0	0	77.0	55.7	132.7
12	0	0	0	0	44.5	0	44.5
13	0	0	0	0	31.0	0	31.0
14	0	0	0	0	0	0	0
15	0	0	0	0	39.0	0	39.0
16	47.5	0	0	0	66.0	0	113.5
17	48.0	0	0	0	0	0	48.0
18	17.0	0	0	0	0	0	17.0
19	13.5	0	0	0	0	0	13.5
20	33.0	0	9.9	0	0	0	42.9
21	0	0	34.2	0	0	0	34.2
22	0	0	18.8	0	0	0	18.8
23	0	0	0	0	0	0	0
24	0	0	54.5	0	0	0	54.5
25	0	0	0	0	0	0	0
26	0	0	29.8	0	0	0	29.8
27	0	0	0	0	0	0	0
28	45.5	0	0	0	29.5	0	75.0
29	0	0	0	-	34.0	0	34.0
30	0	0	54.9	-	34.0	0	88.9
31	-	0	25.5	-	38.0	-	63.5
TOTAL	233.5	381.5	227.6	0	456.0	261.7	1,560.3

been published in Thomas J. Henderson, "A Ten Year Non-Randomized Cloud Seeding Program on the Kings River in California", Journal of Applied Meteorology, vol. 5, No. 5, October 1966.

In addition to project operations, Atmospherics Incorporated conducted research operations under a cost-sharing contract with the National Science Foundation. Research activities included:

- Evaluation of Kings River Weather Modification Project.
- Tracking of silver iodide plumes to leeward of airborne and ground generators.
- Detection of possible changes in air potential as related to cloud seeding.
- Study of natural background condensation nuclei.
- Investigation of surface wind flow patterns in area of ground generators.
- Investigation of surface temperature profile at elevations of 300 to 6000 feet.
- Examination of ice crystals in operational area for possible changes in physical characteristics related to cloud seeding.
- Radar observation and filming of clouds.
- Acquisition of ambient temperatures during seeding flights.

Equipment provided by the National Science Foundation for the research effort is listed in Table 14. Selected results of the research program are summarized below.

Tracking studies indicate that silver iodide plumes originating either on the ground or from airborne sources do not appear to follow any specific pattern over the up-slope orographic areas of the Sierra Nevada. Some ground generator locations were changed to take advantage of such plume patterns as were indicated by the tracking studies.

Studies of condensation nuclei have shown that the level of condensation nuclei concentration in the San Joaquin Valley area adjacent to cloud seeding programs has increased by at least an order of magnitude during the period 1964-67. No specific evidence that this increase affected precipitation mechanisms in the Sierra was found. However, measurements showed that many of the extra particles do act as cloud nuclei.

Studies of changes in air potential indicated that a change in electrical activity apparently always took place almost immediately following the aerial application of seeding material to cloud formations in the vicinity of air potential indicators. Also, measurements made leeward of generator sites when pyrotechnic seeding materials were in use indicated a change in electrical activity.

Studies of surface wind patterns indicated that a surface wind analysis appears necessary for the design of an effective weather modification program in mountain areas. However, very little apparent correlation was found between the speed and direction of surface winds and the winds a few hundred feet above a given surface elevation. Wind analysis showed that two ground generator locations should be changed. The analysis also indicated a possibility that during a number of storm periods since 1965 one

TABLE 13. SUMMARY OF OPERATIONS, PROJECT 21-67-1

Month	Seeding periods	Days of seeding	Hours of seeding
November	4	6	233.5
December	3*	6	381.5
January	4	7	227.6
February	0	0	0
March	6	12	456.0
Apr	4	8	261.7
TOTAL	21	39	1,560.3

*Only 2 of the 3 storms were seeded.

TABLE 14. RESEARCH EQUIPMENT: ATMOSPHERICS INCORPORATED—NSF RESEARCH PROGRAM

Quantity	Equipment
1	Meteorology Research Inc. (MRI) Portable Cold Box
2	Gardner Associates Small Particle Detectors
2	MRI Air Potential Indicators
2	MRI Mechanical Weather Stations
1	Keystone 16 mm Modified Radar Camera
1	Kodak K-100 16 mm Modified Time Lapse Camera
12	Brooklyn Miniature Recording Thermometers

of the control streams (Kern River) was affected by ground generator seeding for the Kings River Weather Modification Project.

Data accumulated through radar viewing constitute strong evidence that precipitation can be initiated from nonprecipitating cumulus cells which develop over the Sierra during fairly active postfrontal periods. Time-lapse photography -- though not entirely successful due to pollution levels -- confirms this conclusion. When cloud bases were visible from the radar station, precipitation was observed falling from the base of seeded clouds which were nonprecipitating prior to treatment.

More detailed information regarding the research effort may be found in "Final Report to the National Science Foundation, Washington D.C.: Physical Studies of Winter Storm Mechanisms as Related to Cloud Seeding Efforts in the Sierra Range of California, ...", a report prepared by Atmospherics Incorporated.

Project Sierra Cumulus (21-67-2)

Between May 17, 1967, and September 25, 1967, Atmospherics Incorporated (License 21) conducted weather modification project operations on behalf of Fresno State College Foundation. Project Sierra Cumulus was a continuation of Project Orographic Cumulus (operated during the 1965-66 season). Project Sierra Cumulus was a research project designed to investigate the possibility of initiating and enhancing precipitation from summer orographic cumuli developing over the Southern Sierra.

The potential area of operations included the watersheds of the Stanislaus, Mokelumne, Tuolumne, Merced, San Joaquin, Kings, Kaweah, Tule, and Kern Rivers. However, to preserve the Merced River drainage as a control area which has never been seeded or, insofar as can be determined, affected by seeding operations, no seeding flights were conducted in this area.

Project equipment included a turbocharged Piper Aztec "C". This twin-engine aircraft was equipped with navigation and communications systems including dual-omni, distant measuring equipment, and radar transponder. Seeding equipment aboard the aircraft included a dry ice pellet dispenser and wing racks for mounting and firing various pyrotechnic nucleation devices. In Project Orographic Cumulus during the 1965-66 season, a similarly equipped Piper Apache aircraft was used for seeding.

Monitoring equipment included a 3.2-cm weather radar system operating on a frequency of 9375 megacycles. The radar had a peak power of 50 kilowatts and a maximum range of 200 statute miles. The radar system had two 7-inch plan position indicators. One of the indicators was used for general viewing, and the other, for data acquisition through time-lapse photography. Positioned around the second indicator was an illuminated digital display showing date, time, antenna angle, and range. During the period of operations, the radar system logged approximately 265 hours, and 1,200 feet of 16-mm Tri-X cine film were exposed.

Four types of activity were included:

- Conduct of a cloud census and tabulation of total days which produce cumuli suitable for seeding.
- Aerial application of silver iodide or dry ice pellets to a single randomly chosen cumulus within a pair of cells.
- Aerial silver iodide seeding over preselected high-altitude subbasins within the larger watersheds of the southern Sierra.
- Identification of possible effects of seeding operations.

Twenty-nine seeding flights (a total of 91 hours) were made. In several cases, more than one activity was performed during the same flight. On 25 of the flights, test-case seeding of cumuli in a pair of cells was conducted. Three other flights were made for test-case seeding, but no seeding was conducted due to unsatisfactory conditions. On ten flights, seeding over high-altitude subbasins was conducted. One other flight was made for subbasin seeding, but it was aborted due to lack of clouds. Aircraft operations are summarized in Table 15.

A major phase of project field operations was the seeding of randomly chosen cumuli developing over the Southern Sierra. An effort was made to select nonprecipitating cumulus turrets in excess of 5,000 feet thick. The developing cumulus turrets were chosen in pairs. It was attempted to select pairs whose members had similar growth and volume characteristics. One turret of each pair of cumuli was randomly selected for seeding. Either dry ice pellets were applied at the top of the chosen cloud, or silver iodide was applied at its lower levels.

During the project, 25 test cases involving the seeding of such a randomly chosen cumulus were conducted. In 12 of the cases, dry ice was used as the nucleation agent. In 13 of the cases, silver iodide was used. A total of 137 pounds of dry ice and 1,284 grams of silver iodide was dispersed. In 19 of the 25 seeded clouds, precipitation was observed after seeding. In ten of these cases, precipitation reached the ground. Precipitation was observed in the untreated clouds of the pairs in only two cases, and only in one of these cases did precipitation reach the ground. The project report prepared by Atomospherics Incorporated stresses the fact that dry ice was used as the nucleation agent in five of the six cases when precipitation was not observed subsequent to seeding.

TABLE 15. AIRCRAFT OPERATIONS, PROJECT 21-67-2

Flight No.	Date	Take-Off	Land	Flight Time	Operation
1	5/17	1449	1820	3.5	Pairs Test Cases #1 & #2
2	5/22	1358	1720	3.3	Pairs Test Cases #3 & #4
3	5/23	1537	1749	2.2	Test Case conditions unsatisfactory
4	6/14	1529	1835	3.1	Pairs Test Case #5
5	6/15	1559	1840	2.7	Pairs Test Case #6
6	6/16	1251	1627	3.6	Pairs Test Case #7
7	6/17	1204	1628	4.4	Pairs Test Cases #8 & #9
8	6/18	1242	1617	3.6	Pairs Test Case #10
9	7/6	1330	1712	3.7	Pairs Test Cases #11 & 12
10	7/7	1327	1654	3.4	Pairs Test Cases #13 & 14
11	7/12	1332	1648	3.3	Area Test Case #1
12	7/13	1316	1652	3.6	Area Test Case #2
13	7/14	1204	1626	4.4	Pairs Test Case #15
14	7/17	1129	153[illegible]	4.1	Pairs Test Case #16
15	7/24	1329	1658	3.5	Pairs Test Cases #17 & 18
16	7/28	1141	1509	3.5	Pairs Test Case #19 Area Test Case #3
17	7/29	1038	1454	4.3	Pairs Test Cases #20 & 21
18	7/30	1054	1500	4.1	Pairs Test Cases #22 & 23
19	8/17	1009	1309	3.0	Test Case conditions unsatisfactory
20	8/21	1410	1641	2.5	Pairs Test Cases #24 & 25
21	8/22	1240	1440	2.0	Test Case conditions unsatisfactory
22	8/23	1103	1308	2.1	Area Test Case #4
23	8/24	1045	1344	3.0	Area Test Case #5
24	/25	1115	1310	1.9	Area Test Case #6
25	8/26	1228	1400	1.5	Abort area seed--no clouds
26	9/3	1152	1530	3.6	Area Test Case #7
27	9/18	1551	1719	1.5	Area Test Case #8
28	9/24	1153	1459	3.1	Area Test Case #9
29	9/25	1526	1758	2.5	Area Test Case #10
			Total	91.0 hours	

A second phase of project field operations was the seeding of summer clouds over selected high-altitude subbasins within major river watersheds. Greater emphasis was placed on subbasin area seeding than during the 1965-66 season. This shift in emphasis stemmed, in part, from an examination of historic hydrologic records. The results of the examination suggested that the effects of seeding might be more definitively assessed if experiments were designed to influence the measured flow from larger areas than those affected by cloud pairs seeding. Also, it was found that many subbasins in the Southern Sierra may be efficient producers of water during summer. Numbers of precipitation occurrences are high, and basin characteristics seem to lend themselves to relatively high runoff per inch of precipitation.

Subbasin area seeding was begun at the end of the snowmelt season, becaust at that time individual hydrographs of subbasins indicate minimal daily flows. During the 1966-67 season, the beginning of subbasin area seeding was considerably delayed due to abnormally high streamflow resulting from a snowpack nearly 200 percent of normal. The end of the snowmelt season -- which usually occurs by August 13 -- did not occur until the first week of September. Seeding operations were conducted to the windward of the subbasin under study, so that the major effects of seeding were largely confined to that subbasin. Seeding was carried out at cloud base at high-altitude areas of the Sierra when at least 50 percent of the area of operations for a subbasin was covered by clouds more than 5,000 feet thick. No randomization was included in subbasin seeding. Evaluations were based on hydrologic data.

Three cases of subbasin area seeding were conducted before August 23. Snowmelt flows were still occurring. After August 23, seven cases of subbasin area seeding were conducted, all in the Bear Creek watershed above Lake Thomas A. Edison. Silver iodide was used as the

nucleation agent in nine of the ten subbasin area seeding cases. A total of 2,570 grams of silver iodide was dispersed. For the remaining case, 18 pounds of dry ice pellets were dispersed at cloud top. In all ten cases of subbasin area seeding, precipitation occurred following application of the nucleation agent. In all cases, precipitation reached the ground. Subbasin areas are shown in Figure 10. Area seeding operations are summarized in Table 16.

On the basis of the results of operations during the 1965-66 and 1966-67 seasons, certain general conclusions were drawn regarding summer cumuli in the Southern Sierra. It was considered obvious, on the basis of test-case seeding of cloud pairs, that precipitation could be initiated from nonprecipitating cumuli throughout the Southern Sierra. The results of subbasin area seeding operations led to the conclusion that precipitation could be enhanced within high-altitude subbasins through seeding of summer cumuli. Moreover, a tabulation of maximum cloud activity during this period clearly indicated preferred zones for development of cumuli in the Southern Sierra.

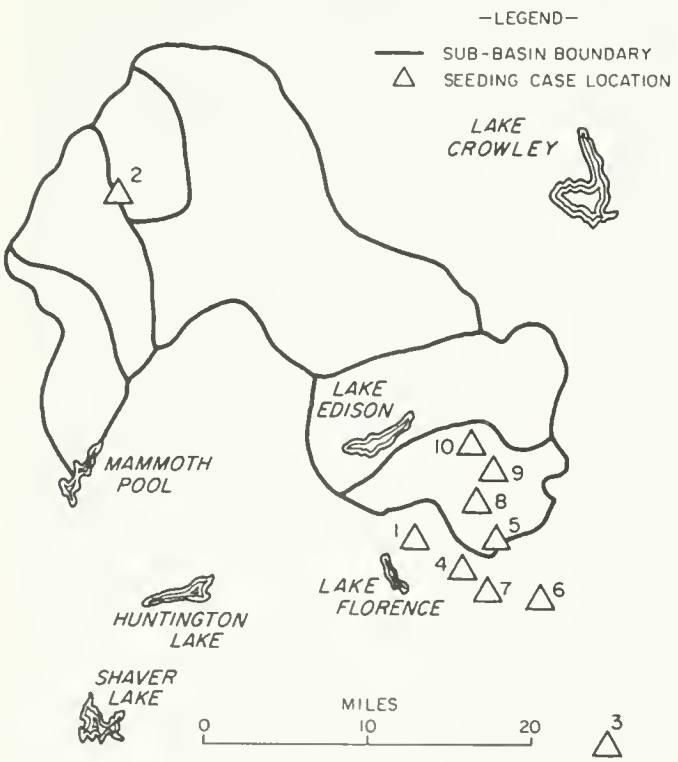


Figure 10. Location of Sub-Basin Areas, Project 21-67-2

A series of aerial photographs was taken during each cloud pairs and subbasin area seeding test case. In the 25 test cases dealing with cumulus pairs, 213 photographs were taken. During the subbasin area seeding cases, 86 photographs were obtained.

Atmospherics Incorporated submitted to the Department a report entitled, "Project 'Sierra Cumulus' -- 1967 Report".

Additional information may be found in a summary report by Atmospheric Water Resources Research, Fresno State College Foundation, entitled, "A Research Project Conducted in Southern Sierra Nevada Watersheds". This report is reprinted, by permission of Atmospheric Water Resources Research, in Appendix A.

Upper Santa Ana River Watershed Weather Modification Project (22-67-1)

Between January 22, 1966, and April 22, 1967, San Bernardino Valley Municipal Water District (License No. 22) conducted weather modification project operations on its own behalf. This project was conducted to increase precipitation in the Upper Santa Ana River watershed. The target area was the area of the Santa Ana River watershed lying within San Bernardino County. The specific shape of the target area was changed for the 1966-67 season. During the 1965-66 season, the northwestern arm of the target area extended to a point

TABLE 16. SUMMARY OF AREA SEEDING OPERATIONS, PROJECT 21-67-2

Area Case Number	Date	Cloud Base Elevation msl(feet)	Cloud Base Temp. (°C)	Operation Cloud Altitude msl(feet)	Operation Cloud Temp. (°C)	Amount of AgI (grams)	Area
1	7/12	14,600	-0.5	14,700	-0.5	84	2 sq. mi.
2	7/13	12,700	6	13,000	3	56	5 sq. mi.
3	7/28	13,400	4	24,000	-18.5	18**	Unknown
4	8/23	14,000	1	14,000	0.5	240	"
5	8/24	13,500	2	13,500	2	250	"
6	8/25	12,600	3	12,500	3	480	"
7	9/3	10,000	9	10,000	9	490	Widespread
8	9/18	11,000	1.5	11,000	1.5	240	"
9	9/24	11,700	0.5	12,000	0	480	"
10	9/25	13,700	-2	13,700	-2	250	"

*Precipitation reached the ground in every case.
**Pounds of dry ice.

somewhat north of Cajon. During the 1966-67 season, the Cajon area was not considered part of the target area, and the generator formerly at Cajon was relocated.

A significant portion of the target area is over 3,000 feet in elevation. The northern portion of the area, bounded by the San Bernardino Mountains, reaches elevations approximating 5,000 feet. The southwest corner of the target area has an elevation of less than 1,000 feet. The eastern portion of the target area lies mostly above the 3,000-foot level, and some portions are above 8,000 feet in elevation. The Santa Ana River and its tributaries, Mill Creek and City Creek, lie in the eastern portion of the target area.

Equipment was operated primarily in the southern portion of San Bernardino County and the western portion of Riverside County. No effect on any area outside the target area was foreseen. Project equipment included 17 ground-based generators burning a silver iodide solution. Target area and generator locations are shown in Figure 11.

During April, in addition to generator operation, 50 pyrotechnic seeding devices were ignited on the ground for 4 days of seeding during one storm. No pyrotechnic seeding devices were used during the 1965-66 season. Monthly totals of generator-hours for each project generator are given in Table 17. Distribution of generator-hours by day is given in Table 18.

Four storms -- compared to a total of six storms for the 1965-66 season -- occurred during the project. Two storms occurred in March (one March 31 - April 1)

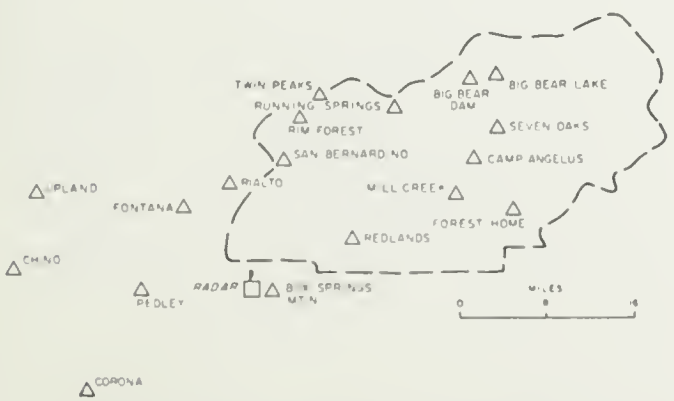


Figure 11. Target Area and Generator Locations, Project 22-67-1

and one for each of the remaining months when seeding operations were conducted.

During the project, 16,158 grams of silver iodide was dispersed: 11,158 grams from

TABLE 17. GENERATOR-HOURS OF OPERATION BY MONTH, PROJECT 22-67-1

Location	Jan	Feb	Mar	Apr	Total
Running Springs	46.25	0	56.75	12.00	115.00
Big Bear Lake Dam	46.25	0	56.75	12.00	115.00
Big Bear Lake City	46.25	0	56.75	12.00	115.00
Seven Oaks	0	0	15.50	10.00	25.50
Angelus Oaks	24.25	0	56.75	12.00	93.00
Forest Home	24.25	0	55.75	12.00	92.00
Mentone	47.00	0	56.25	12.00	115.25
Redlands	46.25	0	63.25	12.25	121.75
San Bernardino	46.00	0	64.50	8.25	118.75
Rialto	24.00	0	59.75	12.25	96.00
Fontana	47.25	0	63.25	12.25	122.75
Riverside	46.25	0	15.25	12.25	73.75
Corona	46.25	0	63.25	12.25	121.75
Chino	24.00	0	17.25	0	41.25
Upland	24.00	0	41.25	0	65.25
Twin Peaks	0	0	56.50	12.25	68.75
Rim Forest	46.25	0	56.25	12.50	115.00
TOTAL	584.50	0	855.00	176.25	1,615.75

TABLE 18. GENERATOR-HOURS OF OPERATION BY DAY, PROJECT 22-67-1

Day	Jan	Feb	Mar	Apr	Total
1	0	0	0	176.25	176.25
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11		0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	170.75	0	170.75
18	0	0	344.00	0	344.00
19	0	0	113.75	0	113.75
20	0	0	0	(6)*	0
21	0	0	0	(14)*	0
22	166.50	0	0	(19)*	166.50
23	106.00	0	0	(11)*	106.00
24	206.25	0	0	0	206.25
25	105.75	0	0	0	105.75
26	0	0	0	0	0
27	0	0	0	0	0
28	0	0	0	0	0
29	0	-	0	0	0
30	0	-	0	0	0
31	0	-	226.50	0	226.50
TOTAL	584.50	0	855.00	176.25	1,615.75

*Number of pyrotechnic seeding devices used at 10 grams AgI per device.

generators and 500 grams from pyrotechnic seeding devices. Project operations are summarized in Table 19.

Lake Almanor Cloud Seeding Project (23-67-1)

Between November 14, 1966, and April 28, 1967, Pacific Gas and Electric Company (License No. 23) conducted weather modification project operations on its own behalf. This project was conducted to gather information on the effectiveness of cloud seeding. Equipment was operated in Plumas, Lassen, and Tehama Counties. The target area was the drainage basin of Lake Almanor, Butt Valley Reservoir, and Mountain Meadows Reservoir in the Northern Sierra. Areas in the Counties of Plumas, Lassen, Shasta, and Tehama were also possibly affected by the project.

Project equipment included 6 radio-controlled generators placed on peaks and ridges above 6,000 feet in elevation. Because valley locations in mountainous areas are often subject to inversions and local channeling, the high-elevation location of generators permitted more accurate estimates of plume trajectories. Generators were divided into East (Ohio Ridge, Dyer Mountain) and West (Humboldt Summit, Humbug Summit, Butt Mountain, Stover Mountain) groups, and seeding was conducted on a randomized basis. At a rate of 25.4 grams of silver iodide per hour per generator, the generators released silver iodide crystals which acted as ice nuclei at temperatures below -5°C. Target area, generator, and precipitation station locations are shown in Figure 12.

TABLE 19. SUMMARY OF OPERATIONS, PROJECT 22-67-1

Month	Seeding periods	Days of seeding	Hours of seeding
January	1	4	584.50
February	0	0	0
March	2	4	855.00
April	1	5*	176.25
TOTAL	4	13*	1,615.75

*Includes 5 days seeding by pyrotechnic devices.

Monthly totals of generator-hours for each project generator group are given in Table 20. Distribution of generator-hours by day is given in Table 21.

A total of 75 storms occurred during the period of project operations. From November through February, between 6 and 13

TABLE 20. MONTHLY TOTALS OF GENERATOR HOURS FOR EACH PROJECT GENERATOR GROUP, PROJECT 23-67-1

	Generator Hours*				
	West Burners	East Burners	All Burners	Dates Generators Were Inoperative	East or West Burners
Nov	352.6	66.0	418.0		
Dec	506.0	88.0	594.0	Humboldt Summit 12/3	West
				Humbug Summit 12/23	West
Jan	473.0	110.0	583.0	Humboldt Summit 1/30	West
				Humbug Summit 1/28	West
				Stover Mtn. 1/4,25	West
Feb	242.0	22.0	264.0	Humbug Summit 2/15	West
				Stover Mtn. 2/15	West
Mar	763.5	132.0	895.5	Humboldt Summit 3/26	West
				Butt Mtn. 3/17, 20,28	West
				Stover Mtn. 3/15,16	West
				Ohio Ridge 3/30	East
				Dyer Mtn. 3/13**	East
Apr	814.0	132.0	946.0	Humboldt Summit 4/10,11,23	West
				Humbug Summit 4/25	West
				Stover Mtn. 4/27,28	West
Total	3,150.5	550.0	3,700.5		

* In the 1965-66 season, 2,277 hours were logged during 7 months. Heaviest seeding occurred during December (506 hours), February (561 hours), and March (440 hours); lightest seeding occurred in May (88 hours). In the 1964-65 season, 1,248.5 hours were logged during 7 months.

** Operated only 4.5 hours on 3/31.

Figure 12. Target Area, Precipitation Gages and Generator Locations, Project 23-67-1

storms occurred each month, 19 storms occurred in March and 20 in April. During the 1965-66 season, 70 storms occurred, ranging from fewer than 5 to 17 per month.

During the project, 94,017 grams of silver iodide was dispersed. Project operations are summarized in Table 22.

This project constituted the fifth year of a five-year test program. The Pacific Gas and Electric Company has evaluated the completed program. A paper summarizing the program, entitled "Pacific Gas and Electric Company's Weather Modification Program and Accomplishments", by Leon M. Hunsaker and Warren L. Scott was presented at the American Society of Civil Engineers' Irrigation and Drainage Division Conference in Sacramento, California, November 2, 1967. Additional information on the results of the project may be found in a paper by Margaret L. Mooney and George W. Lunn, entitled, "The Area of Maximum Effect Resulting from the Lake Almanor Randomized Cloud Seeding Experiment", presented at the Western Snow Conference, Lake Tahoe, Nevada, April 17, 1968.

TABLE 21. GENERATOR-HOURS OF OPERATION BY DAY, PROJECT 23-67-1

Day	Nov	Dec	Jan	Feb	Mar	Apr	Total
1	0	88.0	0	44.0	44.0	0	176.0
2	0	66.0	0	0	0	0	66.0
3	0	33.0	0	0	0	0	33.0
4	0	66.0	33.0	0	0	44.0	143.0
5	0	88.0	22.0	0	0	88.0	198.0
6	0	0	0	0	0	44.0	44.0
7	0	66.0	0	0	0	0	66.0
8	0	0	0	0	0	0	0
9	0	66.0	0	0	44.0	22.0	132.0
10	0	44.0	0	0	66.0	77.0	187.0
11	0	0	0	0	88.0	33.0	121.0
12	0	0	0	0	88.0	0	88.0
13	0	44.0	0	44.0	55.0	22.0	165.0
14	44.0	0	0	44.0	0	44.0	132.0
15	66.0	0	0	22.0	33.0	0	121.0
16	0	0	0	0	33.0	22.0	55.0
17	0	0	0	44.0	33.0	88.0	165.0
18	0	0	0	0	22.0	44.0	66.0
19	66.0	0	44.0	0	22.0	0	132.0
20	88.0	0	88.0	0	33.0	44.0	253.0
21	66.0	0	66.0	0	0	44.0	176.0
22	0	0	22.0	0	22.0	22.0	66.0
23	0	33.0	88.0	0	44.0	77.0	242.0
24	0	0	88.0	22.0	0	66.0	176.0
25	0	0	33.0	44.0	44.0	33.0	154.0
26	0	0	22.0	0	33.0	44.0	99.0
27	0	0	0	0	0	55.0	55.0
28	88.0	0	33.0	0	55.0	33.0	209.0
29	0	0	0	-	0	0	0
30	0	0	22.0	-	55.0	0	77.0
31	-	0	22.0	-	81.5	-	103.5
TOTAL	418.0	594.0	583.0	264.0	695.5	946.0	3,700.5

TABLE 22. SUMMARY OF OPERATIONS, PROJECT 23-67-1

Month	Seeding periods	Days of seeding	Hours of seeding
November	11	6	418.0
December	16	10	594.0
January	17	13	583.0
February	7	7	264.0
March	26	19	895.5
Apr	26	20	946.0
TOTAL	103	75	3,700.5

Santa Clara Valley Cloud Seeding Project (26-67-1)

Between November 6, 1966, and March 31, 1967, Santa Clara Valley Water Conservation District (License No. 26) conducted weather modification project operations on its own behalf. This project was conducted to regulate precipitation in parts of Santa Clara County. Equipment was operated in Santa Clara, San Mateo, Santa Cruz, Monterey, and San Benito Counties. Areas adjacent to the target area which were possibly affected by the project were parts of Alameda, San Mateo, Santa Cruz, Monterey, San Benito, Merced, Stanislaus, and San Joaquin Counties.

Project equipment included 21 ground-based generators of the Modified Starfire type. These generators burned a 2.75 percent solution of silver iodide at a rate of approximately 25 grams per hour per generator, one gram producing more than a quadrillion nuclei. The generators were usually located to the windward side of the crest of the Santa Cruz Mountains, or near the crest. The positioning of generators in this way permitted silver iodide particles to be carried upward by rising air currents. Two generators were moved from their 1965-66 season locations, and one new generator site was established. Generator No. 9 was moved about 2 miles south of its 1965-66 season location. Due to insufficient nuclei coverage of the Uvas, Chesbro, Anderson, and Coyote watersheds, generator No. 15 was moved to a site about 3 miles northeast of Watsonville, and a new generator (No. 21)

was established at a site about 4 miles north of Corralitos. Target area and generator locations are shown in Figure 13.

A trailer coach on Canoas Hill (elevation 440 feet) about 5 miles south of San Jose served as operational headquarters. Monitoring equipment included a General Electric SBN 13 weather radar set, a facsimile machine linked to the U. S. Weather Bureau circuit for weather maps, and a low-frequency radio for local weather data. A 16-millimeter motion picture camera was used for time-lapse photography of the radar scope to record rain cell movement.

Because of indications, in late January, that district reservoirs on the west side of the Santa Clara Valley would fill without the artificial production of additional rainfall, seeding operations in this area were terminated on January 27. The remaining seeding during the season was conducted in the Anderson-Coyote watershed. Monthly totals of generator-hours for each project generator are given in Table 23. Distribution of generator-hours by day is given in Table 24.

During the project, 13 storms occurred, monthly totals ranging from 4 in November to 1 in February. A total of 44,060 grams of silver iodide was dispersed. A summary of project operations is given in Table 25.

The project was evaluated by a method developed in 1955 by the Cloud Seeding Evaluation Committee of the Greater San Jose Chamber of Commerce and the Weather Modification Company (the licensee originally operating the project). The 1966-67 season is the twelfth year of use of this target-control method of evaluation. Two areas are selected for use in this type of evaluation. One, the target area, is seeded. The second, the control area, is an area which is near the target, but situated so that it will not be affected by seeding.

Precipitation data from 17 control stations and 25 target-area stations were used in evaluating the project. However, data were unavailable for several stations for various lengths of time. For target stations, the percentage of normal for several adjacent stations was computed and this percent-

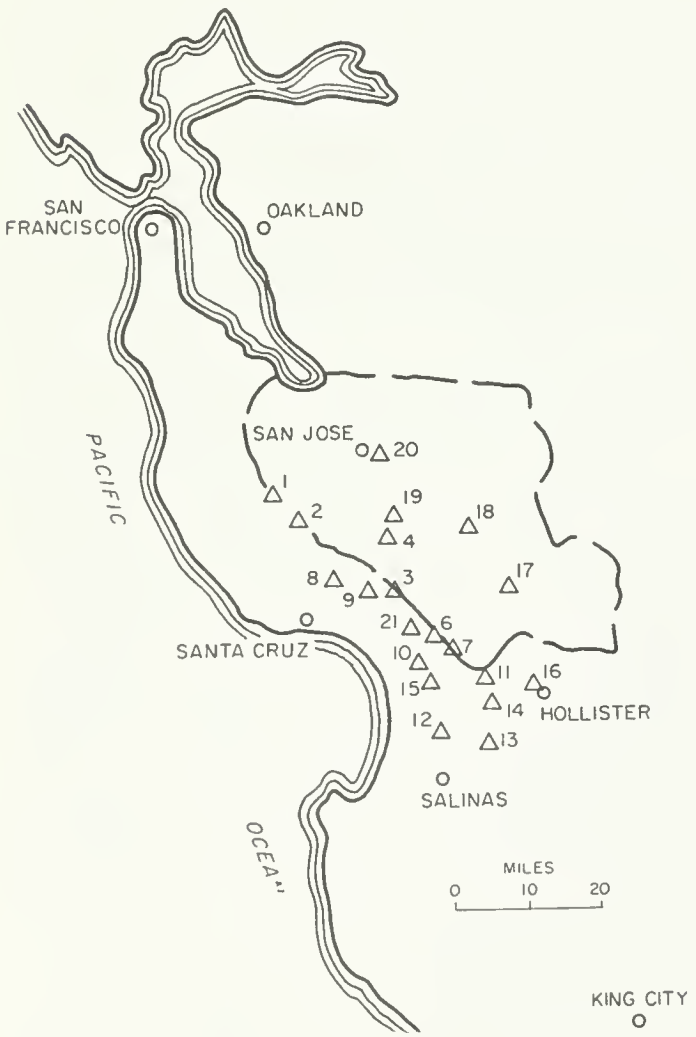


Figure 13. Target Area and Generator Locations, Project 26-67-1

TABLE 23. GENERATOR-HOURS OF OPERATION BY MONTH, PROJECT 26-67-1

Generator Number	Nov	Dec	Jan	Feb	Mar	Total
1	28.2	18.0	0	0	0	46.2
2	43.9	23.5	34.4	0	0	101.8
3	53.1	38.9	37.2	0	0	129.2
4	47.7	36.4	27.0	0	0	111.1
5	42.4	26.9	29.4	0	0	98.7
6	54.6	31.1	36.2	0	0	121.9
7	33.2	22.7	35.4	1.7	52.4	145.4
8	11.8	9.3	0	0	0	21.1
9	16.3	22.9	22.9	0	0	62.1
10	13.8	24.2	0	0	0	38.0
11	29.8	33.4	46.8	0	51.8	161.8
12	13.7	10.9	22.3	0	13.9	60.8
13	10.2	3.2	6.4	0	13.6	33.4
14	17.2	23.6	6.6	0	33.5	80.9
15	30.0	28.1	34.7	0	32.6	125.4
16	0	18.9	17.0	0	22.1	58.0
17	23.6	40.4	51.4	0	55.9	171.3
18	15.0	41.2	50.0	0	55.6	161.8
19	0	7.7	1.8	0	0	9.5
20	0.2	0.3	0	0	1.0	1.5
21	0	0	22.6	0	0	22.6
TOTAL	484.7	461.6	482.1	1.7	332.4	1,762.5

age assigned to the station with the missing data. Ben Lomond was the control station with missing data. Data from Ben Lomond #2 were used for that station for November. All data from each station was used to prevent possible bias introduced by a monthly or storm selection of data.

Average normal rainfall, based on the period 1944 to 1954, was calculated for both control and target stations. Comparison of normal average target rainfall and normal average control rainfall indicated a target-control ratio. Multiplying the average seasonal accumulation of precipitation for the control stations by this ratio, an estimate was made of average accumulation in the target area without seeding. Any recorded precipitation in the target area in excess of this amount was considered to have been induced by seeding.

During the 1966-67 season, several factors complicated the application of the evaluation process. However, during the 1964-65 season and the 1965-66 season, Santa Clara Valley Water Conservation District undertook limited seeding operations in San Benito County. Five control stations were located in the areas of San Benito County seeded in this limited program. The Santa Clara Valley Cloud Seeding Project was evaluated without adjustment for the effects of seeding on the five San Benito County control stations. Also, no adjustments were made to account for the short seeding period on the west side of the Santa Clara Valley during the 1966-67 season. However, a report by Santa Clara Valley Water Conservation District points out that these factors would tend to minimize rather than enlarge evaluated precipitation increases.

The evaluation by Santa Clara Valley Water Conservation District on the accumulation of 12 years of seeding shows an apparent increase of 24.61 inches, or 12.7 percent.

During the summer of 1966, Mr. Lawrence E. Peahl of Taft College, working under a U. S. Bureau of Reclamation grant, also evaluated the project. The evaluation indicated a precipitation increase of 12 percent to 25 percent. Mr. Peahl's report is on file at the Santa Clara Valley Water Conservation District.

The Santa Clara Valley Water Conservation District submitted to the Department a report entitled, "Santa Clara Valley Cloud Seeding Project: Report, 1966-67 Season".

TABLE 24. GENERATOR-HOURS OF OPERATION BY DAY, PROJECT 26-67-1

Day	Nov	Dec	Jan	Feb	Mar	Total
1	0	7.4	0	0	0	7.4
2	0	160.2	0	0	0	160.2
3	0	0	0	0	0	0
4	0	155.1	0	0	0	155.1
5	0	76.1	0	0	0	76.1
6	53.7	62.8	0	0	0	116.5
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	17.5	17.5
11	0	0	0	0	52.3	52.3
12	0	0	0	0	49.6	49.6
13	0	0	0	0	0	0
14	63.7	0	0	0	0	63.7
15	92.8	0	0	0	53.0	145.8
16	42.1	0	0	0	89.8	131.9
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	107.1	0	0	0	0	107.1
20	48.4	0	41.7	0	0	90.1
21	50.2	0	260.2	0	0	310.4
22	0	0	0	0	0	0
23	0	0	8.0	0	0	8.0
24	0	0	77.3	1.7	0	79.0
25	0	0	0	0	0	0
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	26.7	0	10.6	0	0	37.3
29	0	0	35.7	-	0	35.7
30	0	0	48.6	-	51.3	99.9
31	-	0	0	-	18.9	18.9
TOTAL	484.7	461.6	482.1	1.7	332.4	1,762.5

Artificial Modification of Atmospheric Space Charge at Warner Ranch (27-67-1)

Between October 1, 1966, and September 30, 1967, Vista Irrigation District (License No. 27) conducted weather modification project operations on its own behalf. This project is part of a three-year experi-

TABLE 25. SUMMARY OF OPERATIONS, PROJECT 26-67-1

Month	Seeding periods	Days of seeding	Hours of seeding
November	4	8	484.7
December	2	5	461.6
January	3	7	482.1
February	1	1	1.7
March	3	7	332.4
TOTAL	13	28	1,762.5

mental effort in Lake Henshaw Basin. Equipment was operated in the area adjacent to Henshaw Dam in San Diego County. The target area was Warner Ranch in the County. No effect on any area outside the target area was foreseen.

The electric discharge metnod was used for the project. Project equipment included two stainless steel wires, each 0.010 inches in diameter, supported on plastic insulators erected on steel poles placed along the crest of Henshaw Dam. From the dam, the line extended southward, supported by wooden poles. The line was about 5,500 feet long. It was energized at a maximum voltage of 50 kilovolts direct current by a power supply at the dam. A corona-effect discharge of ions, which acted as a nucleation agent, was produced.

The power supply was provided with automatic over-current and over-voltage protection, metering equipment, and a running-time and line-current recorder. Weather instrumentation was also installed at the power supply location.

Atmospheric potential gradient and precipitation were measured and recorded continuously by means of an electrometer and a tipping-bucket rain gage installed at a shop building approximately 4.5 miles east of the line. Precipitation was measured and recorded daily by a network of 12 stations.

The electric discharge unit was operated for 235 days during the 1966-67 season. The unit was operated during every month except September. Continuous operation was attempted, but operations were occasionally interrupted due to breakdowns or installation of additional equipment.

The project has been evaluated by New York Central, Technical Research Department. Various statistical devices -- including target-control ratio, Student's "t" test, probability density functions, and the Wilcoxon statistic -- were used in the evaluation. The results of these tests were not consistent.

For evaluation according to target-control ratios, the Henshaw precipitation station, located to the windward of the line at Henshaw Dam, was selected as a control. Monthly precipitation amounts for seven target stations were compared with those at the Henshaw station, except for months when control precipitation totaled less than 0.02 inches. This eliminated situations in which precipitation occurred at the target but not at the control, and situations in which errors in reading rain gages might be critical. For the V-notch, Ranch House, and Palomar stations (2 and 5.5 miles east, and 9 miles north-northwest of Henshaw Dam, respectively), one extremely large monthly ratio was derived. The large ratio, which was considered nonrepresentative, was dropped from the analysis. Target-control precipitation ratios were greater after than before the line's operation for all except one target station. However, the application of a Student's "t" test of significance showed that these increases could have occurred by chance.

Precipitation at the control station could have been affected by operations. Prevailing winds on the ranch are westerly. Winds at high elevations, however, could be easterly, carrying the charge over the control station and past Mt. Palomar, rather than in the expected direction. This circumstance could account for the indeterminate results of the "t" test

In addition to target-control ratios, rainfall data were used to obtain probability density functions for seven stations. For V-notch, Ranch House, and Palomar stations, preproject and project probability density functions were appreciably different. This seems to indicate that operations have affected precipitation patterns.

The Wilcoxon statistic, which takes into consideration the pattern of increases (six out of seven stations) rather than the statistical significance of the individual increases, indicated a 98 percent probability that operations had affected rainfall distribution. However, this device can give no indication of amounts of increase or decrease.

In addition to legally required minimum data, Vista Irrigation District submitted to the Department an evaluation report entitled, "Report on the Artificial Modification of Atmospheric Space Charge, Warner Ranch, California: August 1, 1965 - June 1, 1967".

APPENDIX A. ATMOSPHERIC WATER RESOURCES RESEARCH, FRESNO STATE COLLEGE FOUNDATION - A RESEARCH PROJECT CONDUCTED IN SOUTHERN SIERRA NEVADA WATERSHEDS

NOTE: Project Sierra Cumulus, an applied research program conducted by Atmospherics Incorporated on behalf of Fresno State College Foundation, is described in Bulletin 16-67 primarily in terms of seeding activities. These are the activities which the Water Code requires licensees to report to the Department. However, the research program undertaken by Fresno State College Foundation involved a wide range of activities besides seeding. A summary report by Atmospheric Water Resources Research, Fresno State College Foundation, entitled "A Research Project Conducted in Southern Sierra Nevada Watersheds", describes the program. The report is reprinted below by permission of Atmospheric Water Resources Research.

The Fresno State College Foundation weather modification research project has the year-around goal of investigating ways to increase runoff to the reservoirs in the Southern Sierra through the means of improved weather modification techniques. Several long-established weather modification projects already existing in this region had shown through analyses of historical stream runoff records that increases were resulting from their efforts. However, a full scale research program studying the physical mechanisms involved in the precipitation process in cloud systems over the Sierra and the technology of how to increase the natural precipitation most efficiently had not been undertaken. In order to fill this need, the Bureau of Reclamation provided funds for the establishment and continued support of the Atmospheric Water Resources Research at Fresno State College in May 1966.

During the first complete October-to-September water year in which the A. W. R. R. operated, most of its activities were concerned with familiarization with already established instrument networks and data available, planning programs of research, selecting and equipping instrument sites and operating a summer research program on cumulus clouds and a winter snow sampling project.

The locations of the many instruments and observation sites pertinent to weather modification activities in the Southern Sierra, including streamflow recorders, were ascertained in the initial effort to establish a working knowledge of data currently being collected and the historical records on file. Through the generous cooperation of many federal, state, local and private organizations, a backlog of data has been compiled and some put in computer-acceptable form which is now available to organizations desiring the use of this file.

The punchcard data, especially the stream runoff figures, has been used extensively by Sierra Hydrotech of Placerville, California (formerly El Dorado Engineering) for A. W. R. R. hydrologic studies. These studies have investigated the historical background of runoff increases in the Sierra and also the basin characteristics of most of the small sub-basins of the Southern Sierra. The latter studies were primarily concerned with runoff occurrences from summer rainfall. This research was based on daily streamflow levels after the end of snowmelt each year and showed the number of summer storm occurrences, volume of runoff and the amount of precipitation increase per storm occurrence necessary for the increase to be attributable to seeding of cumulus clouds (4). In addition to showing detectability of seeding over certain small basins, runoff "potentials" were assigned to each sub-basin examined. The "potential" was based on vegetative and terrain characteristics which were combined, using a computer program, to provide a rating system for the sub-basin's potential water production from seeding operations. The result indicated that the highest potential for producing usable runoff occurred early in the summer season in the steep, rocky basins closest to the Sierra Crest. Low potentials were assigned to sub-basins composed principally of the vegetated meadow areas which generally occur at the lower elevations.

The program design for A. W. R. R. research was based on cooperation in data exchange and also on coordination between A. W. R. R. activities and those of existing organizations. Many of the research activities planned were oriented around the seeding and data-collecting efforts of the previously established projects and would supplement their work. Observations made on aircraft flights, radiosonde and rabal information, and data obtained by A. W. R. R. instruments are part of this cooperative effort.

The formal planning document published for general distribution (2) was completed for A. W. R. R. by subcontractor Aerometric Research, Inc. of Goleta, California. This planning report developed eight models for approaching the optimization of precipitation production by modification of winter storms in the Southern Sierra. These models, of varying complexity, will be used in modified form to investigate various methods of seeding over a highly instrumented test basin. During this water year most of the emphasis was placed on planning and feasibility studies rather than actual operations.

Initial instrumentation and data collection activities in preparation for future tests on the test basin mentioned in (2) were conducted by subcontractor Weather Science, Inc. of Norman, Oklahoma in conjunction with A. W. R. R. from 15 January to 31 March 1967. Aircraft profiles, radiosonde releases, rabal launches and radar echo studies comprised most of the joint efforts. These were conducted on a limited scale primarily to test methods and techniques which could be used in determining airflow and other important parameters in winter orographic precipitation regimes.

Another program conducted during the winter months was the collection of snow samples which were kept in their frozen condition and then shipped to the Desert Research Institute at the University of Nevada, to be prepared for silver detection analysis. These samples were collected primarily after the occurrence of each winter storm causing snowfall in the mountains. The purpose of collecting these samples was to provide information regarding the occurrence of silver in the precipitation which might be related to seeding activities upwind of the sample sites. This was the first year this collection activity was undertaken and was designed to provide background information on which to base future sampling programs.

A large portion of the first year's activities was concerned with locating instrument sites, preparing them and making preliminary installations. A line of hygrothermographs stretching from the coast into the Sierra was the first network installed. Mechanical weather stations measuring temperature and wind were located in Tuolumne Meadows, Florence Lake and Wishon Dam. A crystal replicator was also operated at Florence Lake during the winter. The Wishon site was the location of the first telemetered storage precipitation gage in the A. W. R. R. network. Since then, installation sites in the Tuolumne River Watershed were prepared for precipitation storage gages, but the telemetry components were not installed. Three sites in the Kings River Basin were chosen during the summer months and telemetry capable of transmitting temperature, dew point and stored precipitation to the A. W. R. R. base receiving station was partially installed. The above instruments either recorded data continuously on strip charts or transmitted it upon interrogation by the base station.

A. W. R. R. facilities also included M-33 and TPS-1D radars which were used for wind profile and aircraft-tracking purposes during both winter and summer project operations. Two SMQ-1 radiosonde units were also used during these periods to obtain the temperature and humidity profiles necessary for the project models.

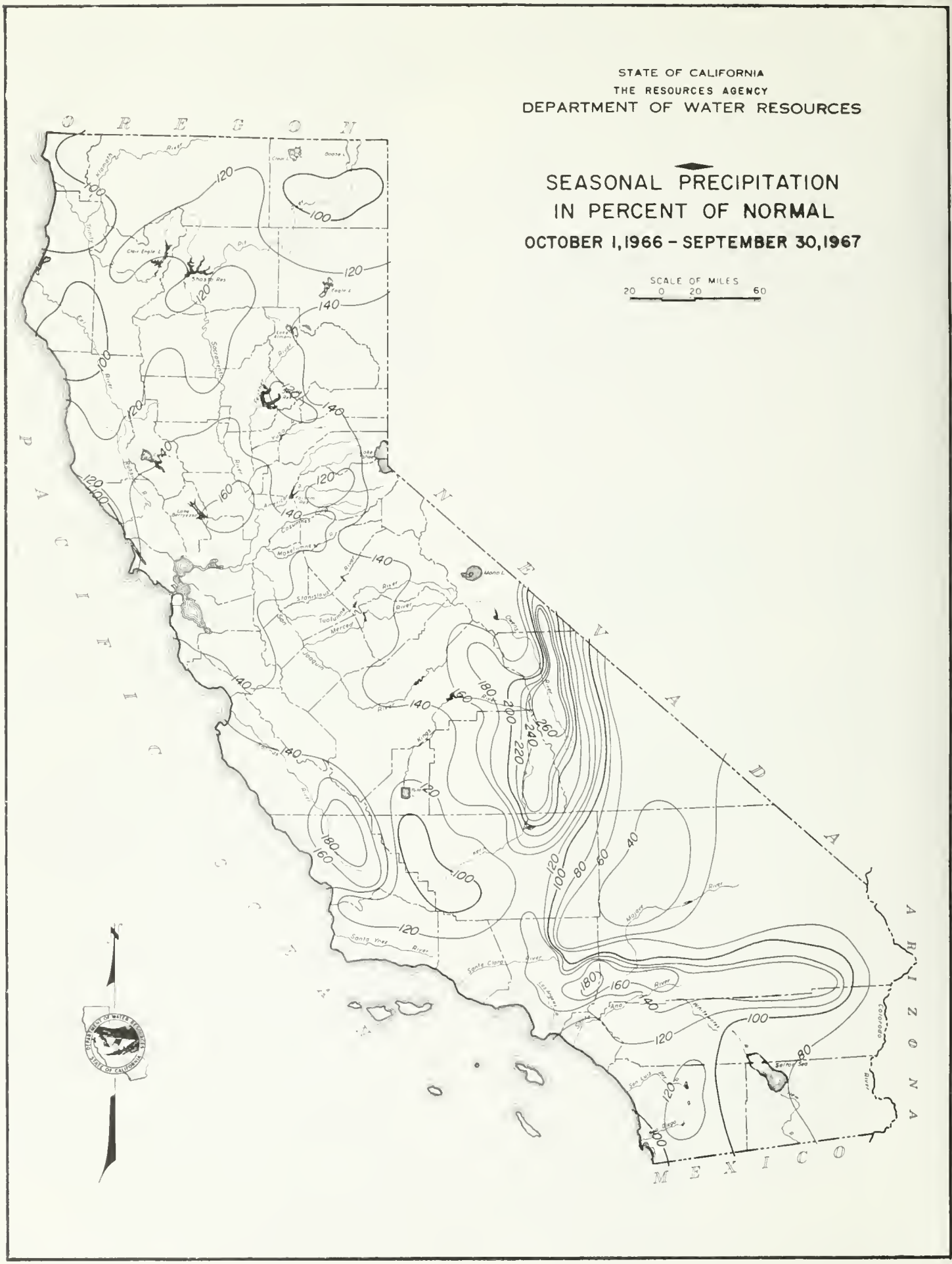
The only program that involved seeding was conducted during May through September on the orographic cumuli which occur almost daily over the Sierra Nevada. Both A. W. R. R. and its subcontractor for this project, Atmospherics, Incorporated, of Fresno, California made observations which contributed to this project, as well as utilized data available through cooperating agencies. Radiosonde and radar wind observations, time-lapse cloud photographs, and weather map analyses were made by A. W. R. R. and used for making forecasts and other analyses. Atmospherics used their radar to determine precipitation patterns, and their aircraft to obtain airborne observations, photographs and temperature profiles as well as to conduct the seeding tests.

These tests consisted of one of a pair of cumulus clouds being seeded while the other remained as the control. Activity of the seeded cloud was compared to that in the unseeded cloud as an indication of the effects of the seeding process. During the summer research period, twenty-three documented pairs were investigated. Seventeen cases produced precipitation from the test cloud while only one control cloud showed evidence of precipitation.

Another portion of the summer program was designed around the seeding of a small high-elevation sub-basin in an attempt to measure the amounts of precipitation which could be attributable to the seeding. Considerable effort was expended by Sierra Hydrotech of Placerville, California, in designing an evaluation program to detect increases in streamflow and to determine the relationship of these increases to the area seeding efforts. Due to the length of time in which streams remained influenced by snowmelt, the operational testing of this phase of the summer project was only started in 1967 and will be continued in Summer 1968.

Reports, Presentations, and Publications, October 1966 to September 1967

1. A.W.R.R., 1967: Sierra Cumulus Project I - Summer 1966.
2. Elliott, Hovind, Thompson, 1967: Design of a Southern Sierra Cloud Seeding Test Program.
3. Evans, 1967: A Report on the Value of Water in the San Joaquin Valley.
4. Hannaford, Williams, 1967: Summer Hydrology of the High Sierra.
5. Vyverberg, Williams, 1967: Summary of Recent Research in Nucleation.
6. Williams, 1967: Weather Modification as a Watershed Management Tool.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THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SEASONAL PRECIPITATION
IN PERCENT OF NORMAL
OCTOBER 1, 1966 – SEPTEMBER 30, 1967
SCALE OF MILES
20 0 20 60
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NEVADA
ARIZONA
MEXICO
PACIFIC OCEAN

APPENDIX B
SEASONAL PRECIPITATION

Because weather modification operations in some measure reflect precipitation patterns, statewide precipitation for the 1966-67 water year is summarized below. Seasonal and monthly precipitation normals (averages) are based on the 30-year period 1931-1960.

Statewide precipitation during the 1966-67 water year was about 130 percent of normal. Only in the Colorado Desert area was precipitation below average (about 80 percent of normal). The statewide high of about 150 percent of normal occurred in the San Francisco Bay and Central Coastal areas. Precipitation in the North Coastal area was about 110 percent of normal.

The water year began with a very dry October, which was a continuation of a persistent dry regime beginning in January 1966. Light storms began in November; then, in December, a 10-day storm deposited heavy precipitation over the State. In Southern California, these storms contributed enough rainfall -- just as during the 1965-66 water year -- to boost totals over the annual average. During the same period, Southern Sierra watersheds experienced a record-breaking warm storm which deposited extremely large amounts of precipitation over the Kern, Tule, and Kaweah drainages. Precipitation varied from 14.47 inches (762 percent of the December normal) at Kern River Powerhouse No. 3 in the Kern River Drainage, to 26.41 inches (430 percent of the December normal) at Springville Tule Headworks in the Tule River Drainage.

A series of storms began in January but was halted because a pressure ridge off the coast diverted subsequent incoming storms to the north. February was dry. However, a low-pressure trough developed off the coast in March and triggered six weeks of storms which boosted total water year precipitation well above normal and which deposited heavy snow in the mountains. Of 211 snow courses measured in May 1 surveys, 139 had the greatest water contents ever observed for that date.

Seasonal precipitation in percent of normal is shown in Figure 14.

More detailed information on precipitation and general water conditions in California during the 1966-67 water year may be found in Department of Water Resources Bulletin No. 120-67, "Water Conditions in California: Fall Report, October 1967".

Santa Clara County Flood Control and Water District's Cloud Seeding Operational trailer and radar antenna.

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